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Technical Document 512

ADVANCED UNMANNED SEARCH SYSTEM (AUSS) DATA HANDLING AND DISPLAY STUDY

BH Kishimoto

June 1982

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NAVAL OCEAN SYSTEMS CENTER
San Diego, California 92152

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inches (in)	mm	25.4
feet (ft)	m	$\sim 3.05 \times 10^{-1}$
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This work is part of an effort to develop an unmanned deep-ocean search system for the Navy. The goal of the entire program is to extend present capabilities significantly. The direction of this study is specifically toward the development of the data handling system (data display, processing, and storage). This document presents a state-of-the-art survey relating to the requirements of undersea search systems, provides engineering guidelines for system selection and design, recommends system requirements on the basis of research results, and identifies some of the critical developmental issues.

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CONTENTS

1 INTRODUCTION

This work is part of an effort to develop a deep-ocean search system for the Navy. The objective of this task is directed specifically toward the development of the data handling system, which will provide the functions of target detection, classification, and identification. The approach is to accumulate a definitive body of knowledge that will enable the selection, specification, and procurement of a set of data handling components for an unmanned system with optimum deep-ocean search capability.

This effort was stimulated by a desire to improve the performance of existing data handling systems in processing the overwhelming volume of data normally generated by a search operation. The goal is to bring to light possible sensitive or critical issues relating to the development of an undersea unmanned search vehicle, for the purpose of identifying and resolving all such issues before the start of design or procurement.

Objectives

In summary, the objectives of this study are as follows:

Provide a state-of-the-art survey on data handling systems related to requirements of undersea search systems.

Provide guidelines for the selection, design, and procurement of data handling systems.

Identify critical issues related to the development of data handling systems that can fulfill the slated search mission requirements.

Background

Target information available at any given time is dependent on many factors: environmental characteristics, sensor type, vehicle attitude, etc. It may consist of a voluminous amount of data (navigation track, speed, altitude, etc) relevant or irrelevant to the particular time/situation condition.

The effectiveness of a search system is determined by the net results of many factors, including cost of sensor deployment, sensor characteristics, information processing and display, and operator capability. The cost of sensor deployment includes such factors as logistic expense, energy expenditure, time, cost, and equipment expense.

The time available for decisionmaking will vary with the mission requirement, vehicle, and type of decision throughout the mission as a function of varying vehicle speed, altitude, surrounding topography, etc. The time in which a lost object can be detected, classified, and identified is

used as a basis from which to compare the effectiveness of different search systems (ref 1, 2). The speed of the vehicle (all else being equal) determines the time necessary for search coverage of a given area. Therefore, the decision time (regardless of whether the decision is made by human or machine or both) can be expected to influence the amount of information and data that can be handled and the consequential effectiveness of the system in finding the object of search.

Search systems, as we know them today, generate a large volume of raw data. Increasing the overall search-rate requirement implies increasing the data generation and accumulation rate of raw data. Thus the data handling system as well must be able to cope adequately with the proportional increase.

Currently, all existing underwater data handling search systems include human operators in the loop. As a result, it is difficult to generalize a priori the adequacy of a system strictly on the basis of its hardware/software processing capability. The human operator introduces nonlinearity into the data handling throughput process, mainly because the relationship between information and decisionmaking is not totally understood. Increasing the amount of information presented to the operator can have various effects that are beneficial, neutral, or even degrading to performance. Therefore, the display and data handling system should be designed such that the operator's perceptual capability is not overloaded. The data should be processed and enhanced so as to aid the operator in the performance of the search task.

Data Handling Functions

The data handling system consists of three major functions: display, processing, and storage.

Display. The display function provides the interface or I/O port between the human operator and the search system. It aids the operator in carrying out the search mission objective of finding and locating the target.

Processing. The processing function has two subfunctions: sensor signal processing and data correlation processing. Sensor signal processing is defined as data processing that reconditions, enhances, or refines the sensor output data. Basically, it involves working with the raw or more primitive level of data. Examples of this type of processing are beamforming, filtering to suppress noise or improve detail, and geometrical corrections. Data correlation processing is defined as data processing that correlates or coordinates data from any of a number of sources for a specific purpose. Basically, it involves working with a higher level or more refined form of data. An example is the coordination of data from various different

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1. NOSC TR 437, Advanced Unmanned Search System (AUSS) Performance Analysis, by SB Bryant, 15 July 1979.

2. NOSC TR 375, Advanced Unmanned Search System (AUSS), Preliminary Search Systems Analysis, by CR Gundersen, December 1978.

navigational sources (satellite, transponders, loran-C, Doppler, compass, etc) directed toward automatically steering the ship or vehicle (autopiloting).

Storage. The storage function retains the data generated by the search system for a finite period. The storage process can be temporary, as on the TTL computer memory, or long term, as on a magnetic tape recorder.

Document Organization

In the sections that follow, no attempt is made to identify specific concepts of data handling systems. The reason, fairly well agreed upon, is that the specifications for optimum search (data handling) systems are highly dependent on the particular mission factors (ie target size, location, depth, bottom condition, search area size, etc). Since no one data handling concept can be considered optimum for all possible search mission factors, a more generic approach is presented. This document focuses on a discussion of the various possible components of the data handling system functions (target detection, classification, and identification).

Sections 2, 3, and 4, associated with the three data handling functions, each contain a literature survey on important aspects related to the search function and recommendation guidelines on selection and design criteria. Section 5 discusses system-level aspects and gives broad system design guidelines.

2 DISPLAY FUNCTION

The display system governs how well the operator can perform the search task, and two sets of factors relate to the display system capability to do this. The first set of factors involves the materials and organization of materials which make up the physical characteristics of the display (electronics, lights, optics, materials, etc). It is often referred to as the hardware or component aspect (ref 3). The second set of factors involves the use of the display by an observer or the relationship of the display to other elements that contribute to the use of the display by the observer (system design, human factors engineering, computer technology, etc). It is often referred to as the software or system aspect of the display design (ref 3).

The primary objective of this section is to discuss and bring to light display system variables that affect the image quality of a display system. The quality of a display has been judged historically by its ability to duplicate the real world. Two approaches have been taken in determining image

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3. Luxenberg, HR, and RL Kuehn (ed), Display System Engineering, Inter-University Electronics Series, vol 5, McGraw-Hill Book Company, New York, 1968.

quality: the subjective measure and the objective measure (ref 4, 5). The subjective approach compares the physical measures of image quality with the subjective assessment as determined by a human observer. The objective approach compares the physical measure of image quality with performance variables associated with a particular task. Much work has been done over the years in the area of psychophysics and vision.

There have been many attempts to establish the link between the subjective measures and the objective measures of image quality. This section presents the results of some of these works.

DISPLAY CHARACTERISTICS THAT DETERMINE IMAGE QUALITY

The term "quality" is very broad as used in context to describe a display system. Image quality may have different meanings for different people.

According to reference 6, eight display characteristics are critical and important in specifying any particular display system for optimum human performance:

Frame rate
Contrast ratio
Ambient illumination
Symbol characteristics
Resolution
Bandwidth
Registration
Phosphor type

The following paragraphs define and review some of the display system variables that have been shown to have a significant but often inconsistent effect on operator perceptual performance related to the search and target-acquisition tasks.

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4. Aerospace Medical Research Laboratory Report AMRL-TR-79-7, An Evaluation and Comparison of Several Measures of Image Quality for Television Displays, by HL Task, January 1979.

5. Biberman, LM (ed), Perception of Displayed Information, Plenum Press, New York, 1973.

6. The Bunker-Ramo Corporation Document, Guide to Human Engineering Design for Visual Displays, by D Meister and DJ Sullivan, Canoga Park CA, 30 August 1969, AD693237.

Bandwidth

Bandwidth is defined as the difference between the limiting frequencies of a continuous frequency band. The specification of bandwidth is basic to any display system in that it describes the available resolving power of the system. The bandwidth of a display system is essentially determined by the system vertical, horizontal, and time resolution.

A restriction of bandwidth poses a problem of determining the display design tradeoff between the frame rate (flicker rate or data refresh rate), resolution (number of characters that can be displayed), and dynamic range of the system. In a real world situation, it very often may be desirable to minimize the display transmission requirements (ref 7). There is extensive literature on the development of hardware to do this through transformation of resolution, gray scale, and frame rate (eg SPIE (ref 8) and technical reports sponsored by ARPA over the past 10 years). There is also extensive literature on evaluations of the effects of bandwidth reduction on an operator's perceptual performance. Most of the present work relates to problems relevant to the Remotely Piloted Vehicle (RPV) program (ref 9-15). These studies are referenced merely for future review.

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7. NOSC TD 379, Remote Operator Performance Using Bandwidth Limited TV Displays: A Review and Proposal, by RE Cole and BH Kishimoto, August 1980.

8. Tescher, AG (ed), Efficient Transmission of Pictorial Information, SPIE Proceedings, vol 66, 1975.

9. McDonnell Aircraft Company Report, Human Factor Requirements for Electronic Displays Effects on S/N Ratio and TV Lines Over Target, McDonnell Aircraft Company, St Louis MO, January 1970, AD744486.

10. Naval Weapons Center TP 5025, Image Identification on Television, by RA Erickson and JC Hemingway, September 1970, AD876331.

11. Hughes Aircraft Company Final Report, Operator Performance Evaluation of Mini-RPV Video Image Bandwidth Reduction/Compression Techniques, by ML Hershberger, Culver City CA, June 1976.

12. Hughes Aircraft Company Final Report, Video Image Bandwidth Reduction/ Compression Studies for Remotely Piloted Vehicles, by ML Hershberger and RJ Vanderkolk, Culver City CA, October 1976.

13. Dacom Incorporated Final Report, Video Image Bandwidth Reduction/ Compression, by JB Kriefeldt, B Ball, and G Tisue, Dacom Inc, Santa Clara CA, June 1976, ADA040033.

14. Aeronutronic Ford Corporation Final Report, Video Image Bandwidth Reduction/Compression Study, by E Schmidt, W Spicer, H Watteings, P Wintz, and R. Yutz, Willow Grove PA, February 1976, ADA04033.

15. University of Kansas/Center for Research Inc Report AFL-TR-76-102, Video Bandwidth Compression, by NC Griswold and RM Haralick, Lawrence KS, February 1977, AD106934.

Color

Showing color of a target and resultant imagery on a TV display could make a target more noticeable, therefore easier to detect and identify during a search. The design engineer should be aware of the primary design requirements to provide the proper illuminant with spectral distribution that will maximize the color contrast of the target against the background. Design recommendations on this aspect are presented in more detail in both references 6 and 16.

Reference 17, a summary of a study to assess the use of color as a sonar display parameter, reports that by coding light levels of intensity in a gray scale and comparing that as a baseline with a carefully selected set of eight colors, an effective gain in detectability of signals was obtained with color. Humans are better discriminators of color differences than of intensity differences because the perception of color is the summed outputs of three somewhat independent retinal receivers (ref 18, 19). Reference 17 concludes that color coding increases the amount of usable information available to the observer by increasing the perceptual elements' ability to discriminate.

Reference 20, a study to compare the relative perceptibility of acoustic signal patterns between black-and-white and color displays, reports that color displays were shown to be superior for the perception of patterning, contouring, and equivalent amplitudes and that for discriminating patterns of very weak signals in noise, color displays are equivalent to gray-scale displays.

Contrast Ratio and Ambient Illumination

The establishment of the optimum contrast ratio is related to the ambient illumination surrounding the display. The human eye adapts to a range of about 200:1. The minimum contrast ratio required for the discrimination of two adjoining areas is about 2:1. Applicable military standards specify a minimum of 10:1 (ref 21).

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16. Farrell, RJ, and JM Booth, Design Handbook for Imagery Interpretation Equipment, Boeing Aerospace Company, December 1975, AD106934.

17. Tracor Report, Summary Report on the Assessment of Color as a Sonar Display Parameter: Extension of the Dynamic Range of Color, by TR Evans, Austin TX, November 1968, AD844927.

18. MacAdam, DL, Visual Sensitivities to Color Differences in Daylight, J Opt Soc Am, vol 32, 1942.

19. Feallock, JB, Absolute Judgement of Color in the Federal Standards System, J App Psychol, vol 50, June 1966.

20. NOSC TR 207, Gray-Scale Versus Color Coding of Acoustic Data Images, by RS French, March 1978.

21. Defense Communications Agency, Television Technical Characteristics: Vol I - Picture Generation and Display Equipment, November 1965, AD 805-174.

Contrast ratio and ambient illumination have a direct effect on resolution, phosphor, display brightness, and viewing geometry. The designer must be aware of the interactive effect on the display due to any change of these two factors.

Resolution is sometimes defined in terms of contrast (ref 5). Often resolution is said to occur when the contrast of the peak of crossover of two central disks exceeds certain values (2%, fo example).

Contrast is defined in many different ways. Usually, it is taken to mean the ratio

$$\frac{\text{(brightness of the brighter) - (brightness of the darker)}}{\text{brightness of the brighter}}$$

Reference 22, an Air Force-sponsored study of the role of contrast in the detection-recognition task, held that within limits, high contrast of a target image facilitates identification but that if target contrast is known in advance, low-contrast targets can be found more quickly than can targets with intermediate contrast in a complex background.

Display Size

Reference 5 points out that large target displays (CRT tubes) are not always necessary. For viewing distances of 20 inches, normal for the usual raster, the observer needs an image size of at least 0.08 inch. The observer usually is not going to see anything on the display that is smaller than about 0.1 inch.

If the observer is viewing a 4-inch display, there are only 40 possible 0.1-inch spots across the 4-inch face. So we have only a 40-line system for the search (detection-recognition) process.

Biberman's recommendation (ref 5) for the design process is first to determine what the expected target display space is and how much time will be available, then to design the system (set) accordingly, using either large displays or display magnifications, or perhaps using lower performance sensors to match the display. It makes no sense to provide an 800-line sensor to feed into an effective 40-line system.

Reference 22 points out the importance of scale (size) in the task of target detection and recognition. It states that, with prior target scale information, targets are often found and recognized with fewer resolution elements than are needed when no prior information is available.

Frame Rate

The determination of the rate of refresh or regeneration for a given display is considered by reference 6 as probably the most important aspect of

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22. Self, H, Image Evaluation for the Prediction of the Performance of a Human Observer, presented at the NATO Symposium on Image Evaluation, Kunstlerhaus, Munich, 18-22 August 1969.

display design. Frame rate directly affects flicker, bandwidth, resolution, phosphor, ambient illumination, and display brightness. An important consideration from the human factors aspect is that it is the primary determinant of flicker.

Gray Scale

Gray scale is defined as the rendition of tones on shades of gray across the gamut from black to white. Normally, shades of gray are defined as luminance levels related by powers of 2 (ref 6).

The contrast or display brightness required for an observer to distinguish gray levels is affected by image size, visual time, and brightness difference between the ambient illumination and display brightness.

By determining the highest and lowest steps that can be distinguished, the notion of "dynamic range" of the system can be obtained. A high contrast ratio in a CRT does not necessarily mean that a larger number of gray shades can be produced.

Reference 6 presents studies indicating that to obtain a high contrast ratio at the expense of gray shades hurts performance, particularly for more difficult targets. References 23 and 24 reported the effects of gray scale and the number of scan lines on observer performance. They found that for noiseless conditions of a test scene consisting of vehicle models on a uniform background, performance increased between 3 and 7 bits.

Reference 25 reported tests of six trained pilots on simulated target detection and recognition tasks under three gamma (gray scale) levels. It concluded that changes in the gamma of the TV transfer characteristic did indicate a trend to earlier detection and recognition of targets. For positive contrast targets, high gamma levels tended to increase the contrast inherent in the target/background relationship, thereby enhancing target acquisition.

Number of Scan Lines

Resolution of a display system often is expressed in terms of lines. The limiting spatial frequency that can be resolved by an optical or photographic system is often expressed in terms of lines.

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23. Gaven, JV Jr, J Tavitian, and PA Holanda, The Relative Effects of Gaussian and Poisson on Subjective Image Quality, Appl Opt, vol 10, no 9, p 2171-2178, 1971.

24. Gaven, JV Jr, J Tavitian, and A Harabedian, The Information Value of Sampled Images as a Function of the Number of Array Levels Used in Encoding the Images, Phot Sci Engg, vol 14, no 1, p 16-20, 1970.

25. Martin Marietta Corporation Final Report, Target Acquisition Studies: (1) Two Dimensional Compared with Three Dimensional Targets, (2) Changes in Gamma for TV Displayed, by FD Fowler, M Freitag, DB Jones, and B King, contract N00014-67-C-0340, NR 196-071, January 1971.

The standard for the US commercial television system is 525 lines, 30 frames and 60 fields per second. The common designator of 525 lines for a TV system does not account for scan retrace, which results in a dead time of about 35 lines. Therefore, the actual number is only about 490 lines.

Line-scanned displays such as TV monitors and electrostatic paper recorders are of concern because many search-related sensors (side-looking sonar, forward-looking sonar, etc) are in essence line-scanned devices requiring this type of display.

In 1958, J Johnson proposed the use of levels of target discrimination based on the number of line parts (TV lines) per minimum object dimension. In his work (ref 26) he set up resolution test charts adjacent to the object to be detected, recognized, identified, etc. He then determined the minimum number of line parts per linear dimensions associated with these tasks. His work is considered (ref 5) a bible for much of the conceptual studies for calculating the SNR required to detect, recognize, or identify objects against clear and cluttered background.

Reference 27 reported that increasing the TV lines over targets yielded an increase in performance for both time and correct response over the 4-12 line range but no further performance increase for 12-20 TV lines. Reference 9 reports that the most effective way to improve performance (increasing the number of correct responses while reducing or maintaining false alarms) is to increase the number of TV lines over the target, ie the SNR. Reference 10 reported the measured recognition of geometric symbols and pictures of military vehicles under both direct and TV view with variations in the number of scan lines and the image size. Performance degraded as the number of scan lines decreased. For symbols, the product of size and the number of scan lines was constant, whereas vehicle recognition required a minimum of 10 scan lines per target, subtending at least 14 minutes of arc. In reference 28, simulated air search scenes were used to study the detection of vehicle targets. No decrease was found in target detection down to seven scan lines per target.

Phosphor Type

In CRT displays, the engineer is concerned with screen efficiency, delay time, and color of the phosphor. From the human factors aspect, the latter two have a direct effect upon the resulting human performance.

Delay time or persistence is directly related to the critical flicker rate of the display, thus is related directly to the required frame rate. For

26. Johnson, J, Image Intensifier Symposium, Ft Belvoir VA, October 6-7, 1958, AD220160.

27. McDonnell Aircraft Company Report H398, Observer Performance with TV Imagery: Gray Scale and Resolution, by SH Levine, RA Jauer, and DR Kozlowski, St Louis MO, September 1969, AD744487.

28. Naval Weapons Center TP 5636, Vehicle Detection on Television: A Laboratory Experiment, by GL Craig, April 1974, AD919898.

the purpose of good visual design, short-persistence phosphors are used for high repetition rates (slow trace or spot movements), medium-persistence phosphors are used for general display applications, and long-persistence phosphors are used for sonar and radar type displays. Phosphors that emit color in the middle of the visible spectrum are compatible with human visual capabilities (ref 6).

Registration

Registration is the superimposition of multiple images to form a composite image. As high information density, multicolor displays, and complex overlayed displays come into increased use, the accuracy with which an image is positioned becomes important. Registration is very critical in color displays; registration error can result in display of a wrong color.

Resolution

There is no simple or universally agreed upon definition for resolution. Definitions are dependent on many factors—the type of display, method of generation, etc. Resolution is commonly defined by any of the following: the size of the electron beam spot on the screen, the angular measure of the smallest observable spot in a given pattern, the graininess of the display, and the number of lines per unit distance.

The resolving capability of the human eye determines the minimal necessary resolution level for a display. Optimum human performance is achieved when the system resolves symbols between 12 and 15 minutes of arc and/or between 10 and 12 lines (ref 29).

SNR

Noise in electro-optical circuits is defined as any extraneous voltage accompanying a signal that interferes with detection of the signal. The strength and frequency characteristics of noise depend on circuit design, operating conditions, types of components used, etc. Noise is also introduced from the transmission media, electromechanical machines, or the environment. Errors introduced by transduction devices are also considered noise and can be treated like other noise sources.

SNR relates the simultaneous signal strength and accompanying noise strength at a given point. IEEE defines the relationship as follows:

$$\text{SNR} = \frac{\text{peak signal (volts)}}{\text{rms noise (volts)}}$$

$$\text{SNR dB} = 20 \log \frac{\text{peak signal (volts)}}{\text{rms noise (volts)}}$$

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29. Gould, JD, Visual Factors in the Design of Computer Controlled CRT Displays, Human Factors, vol 10, no 4, August 1968.

At the threshold of visual detection, signals can be seen at SNR values of about 0.01. The bandwidth and system distribution of the noise strongly influence the effect it has on visual performance (ref 16). Noise is more disruptive in narrow bands centered on the frequency of the target.

Symbol Characteristics

Two discrete but associated symbol-related effects affect confusion and clutter. Confusion is known to occur with certain alphanumeric formats (eg Q and O, T and Y). Clutter is one of the major problems faced by present displays. It is simply the result of the overabundance of information. The task facing the operator is to be able to discriminate the information required from the masses of data that have no relevance to the task.

The problem for the display engineer is to determine which data should be displayed when and to whom. These considerations are system-dependent, hence operator-task dependent (ref 6). Therefore, they can be solved only by specific analysis of information requirements, usually possible only through empirical simulation of the exact operational situations.

View Distance

View distance is defined as the distance from the reviewer's eye to the image being reviewed (image distance in a display). It is important because it determines the eye accommodation required to focus the image on the retina. For screen displays, viewing distance also affects the relative size of the retinal image.

Reference 16 summarizes the best of available studies on the relationship between viewing distance and visual performance. The results of the studies, although not in full agreement, suggest a reduction in vision as the target moves either too close or too far away. The point at which visual performance begins to drop as viewing distance is reduced is not clearly defined, but it appears to be somewhere between 1 and 0.5 metres.

Reference 6 recommends a distance of 18 inches for console viewing. It indicates that although performance has been shown to be acceptable in the range of 14 to 18 inches, a viewing distance of less than 16 inches is accompanied by eye strain and fatigue and is therefore not recommended. Arm reach (28-inch maximum) is also an important factor when the operator must use controls on a console panel.

HUMAN FACTORS ASPECT OF DISPLAY SYSTEMS

In any human-operated system, the operators receive information, process it, and take some specific action upon the system. The relationship between the physical dimensions of an input and the observers' perception of that input is not typically homologous. As reference 5 points out, the correspondence often deteriorates as the human operators become overloaded in their task requirements or are presented with information close to their absolute thresholds of sensitivity.

The human perceptual thresholds are estimated by standard psychophysical methods. They are statistical concepts that have been shown to yield values that depend on the given set of experimental conditions. Variations could be caused by any of a number of factors: measurement techniques, the analysis form, and (most importantly) the observers themselves. Therefore, generalization of one threshold value for a particular experiment conducted in a particular laboratory may not be generalized to the field, where an entirely different set of equipment exists, with complete confidence.

Over 300 laboratory experiments, analytical studies, and field tests have been conducted (ref 30) that relate one or more characteristics of a visual display to the performance of a human observer in obtaining information for a search-type display. In general, the researchers have reported in their results the following classifications of observer response:

Detection—said to occur when the observer correctly indicates his decision that an object of interest is in the field of view.

Recognition—said to occur when the observer correctly indicates to which class of objects the detected object belongs.

Discrimination—said to occur when the observer correctly indicates that the singular target of interest is in the field of view.

Reference 30 indicates that it is rare that the observers can consciously separate the classes of response, particularly in a limited-time search situation. Thus one must be careful that the terms used are not considered to reflect different levels of decisionmaking if, in fact, no such differences exist. The tasks of detection, recognition, and discrimination are considered by many researchers to be at least nonindependent, if not equivalent (ref 5).

Several hundred laboratory and analytical studies have been performed to assess the relationship between variations in line-scan display image parameters and observer performance. The conclusions drawn from critical review of these studies (eg ref 30, 31) have indicated that cross-study comparisons are virtually impossible.

The following are some of the display system variables that have been shown to have a significant effect upon operator target-acquisition (information extraction) performance:

Mean luminance
Size
Viewing distance

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30. USAF Report AFAL-TR-67-293, Low-Light-Level TV Viewfinder Simulation Program Phase A: State-of-the-Art Review, by HL Snyder et al, November 1967.

31. Boeing Company Report D162-10116-3, Night and All-Weather Target Acquisition: State-of-the-Art Review Part III: Television and Low-Light-Level Television Systems, by HW Hairfield, May 1970.

Number of active raster lines
Contrast
Scene movement
Gamma
Signal-to-noise levels
Aspect ratio
Raster direction
Video bandwidth
Target and background characteristics
Terrain masking

Individual experiments have examined the effects of these variables singly and in combinations. But because of the inherent interaction (non-independence) among these variables in their effects upon an observer's performance, quantitative combinations can be hazardous even in the presence of good control. In the absence of control, many a posterior attempt to combine such results has proven useless (ref 5).

DISPLAY MEDIA

Display Classification

Displays are often classified by the type of information they present and how they are used in the operational environment (ref 32). The scope of this discussion is limited to display systems that are based on existing unmanned, undersea, search system requirements.

Information Types

The information types most encountered during an undersea search operation are video, graphic, and message.

Video. Video information is best exemplified by modern television. Information is present both at high resolution and with a high update rate. Video display information is generated by search sensors (television, forward-looking sonar, side-looking sonar, etc).

Graphic. Graphic display information is usually alphanumeric and/or in the form of line drawings. Typical examples of graphic display information are navigation track plots, search pattern grids, and bottom contour overlays.

Message. Message information is alphanumeric and presented at a relatively low data rate compared to the other information types. The automatic typewriter and the character display CRT terminal are typical message devices. Typical types of output information are range data, positional data, and speed.

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32. Flat-Panel Display Technology *Annual Report*, prepared by Tri-Service Airborne Display Technology Working Group for the Office of OUSDRE, 15 October 1980.

End-Use

Three current unmanned search systems were examined in terms of their display capabilities and requirements: Deep Tow (Scripps Institution of Oceanography, UCSD), ANGUS (Woods Hole Oceanographic Institute), and the Surface-Towed Search System (STSS) (Westinghouse). The following list shows end uses of the three types of information provided by these systems.

- Video display
  - Target detection
  - Target classification
  - Target identification
  - Colored topography maps
- Graphic display
  - Terrain and contour maps
  - Search coverage tracks
  - Search grid overlays
  - Target and obstacle markings
  - Navigation
- Messages
  - Position information
  - Range
  - Speed
  - Depth
  - Vehicle attitude and status

VIDEO DISPLAY DEVICES

Cathode-Ray Tube Devices

The cathode-ray tube (CRT), in recent years, has become the primary data display medium because of its inherent flexibility and capability to portray many different information formats at very low cost. Since the display format of modern sonar output information is basically similar to that of video TV, CRT devices have been used extensively to display sonar information.

Four major characteristics of CRT devices are of interest to the display engineer: resolution (spot size), luminance, contrast, and phosphor type. Deflection and focus are achieved by electromagnetic and/or electrostatic means. Design choices depend on the amount of material to be displayed and the desired size of the display.

The major disadvantages of CRT devices are their requirements for large physical area of panel space and behind-panel depth and their high weight, power, and cooling cost. To counter these shortcomings, current effort is underway to develop shorter CRTs. Two of these so-called quasi-CRTs are referred to as flatscreen and area cathode. In the flatscreen type, the electrons are extracted from a gas discharge. In the area cathode types, the conventional CRT point source cathode is replaced by an area source cathode consisting of an array of closely spaced filament wires. The depth dimensions of the two types of units have been reported as low as 3 and 2 inches, respectively.

The technology for raster-scan CRT television monitors is well developed. High-resolution professional and industrial monitors feature a broad spectrum of capabilities. Depending on the selection criteria, a broad range may be selected: 500-5000 lines resolution, 4-30 MHz bandwidth, 12 to 25-inch diagonal screen size, etc. The many different characteristic trade-offs offered by this type of display are well documented and are not covered here.

The following are some of the vendors that provide professional and industrial quality high-resolution television monitors: Conrac Division, Covina, CA; Sony Corporation of America, New York, NY; RCA Corp, Lancaster, PA, Hydroproducts, San Diego, CA; LENCO, Inc, Jackson, MI; AYDIN Controls, Fort Washington, PA; De Anza Systems, Inc, San Jose, CA; and Ramtek Corp, Santa Clara, CA.

In undersea search system applications, the main use of the CRT video monitor has been in the areas of remote TV and sonar displays. For remote television video display, the image presented is usually low-resolution (commercial quality) to normal-resolution monochrome video of the ocean bottom. In some cases, as in the Deep Tow system and the STSS system, a slow-scan imaging technique is employed to reduce the bandwidth requirement imposed on the communication system. Basically, a slow-scanned image is a temporal compression in which a snapshot or single video frame is transmitted at a very reduced data rate.

For sonar video, the CRT display is used in one or more of the following modes: A-scan (obstacle avoidance and altimeter), sector or B-scan (obstacle avoidance and search), PPI scan (search), and raster scan (side-looking sonar search display). The following is a list of some of the vendors that offer CRT displays for sonar applications: Wesmar Offshore Systems, Seattle, WA; Edo Western, Salt Lake City, UT; Ametek Straza Division, El Cajon, CA; Klein Associates, Inc, Salem, NH; and UDI, Aberdeen, Scotland.

UDI, Aberdeen, produces the only commercially available video color system. Called the Colour Video Sonar System (CVSS), it was specifically designed to accept sonar signals and to display the data on a video monitor in either monochrome or color format. The video is controlled by a microcomputer and is capable of displaying a variety of display variations through the following keyboard commands: port and starboard side scan, sequential, or centered out; magnification factors 1, 2, 4, 8, or 16; and 16 shades of gray or 16 colors.

Flat Panel Displays

Flat panel displays offer savings in space, weight, power, and cooling as well as longer life. At present, many display technologies are being explored for a variety of different applications. The major interest in this area stems from the military aircraft display group. The need for increased display capabilities to cope with a wide variety of weapons, countermeasures, and complex pilotage problems has led to development of new technologies to replace existing devices such as the CRT and electromechanical displays.

An annual report prepared by a triservice airborne display technology working group (ref 32) on flat panel display technology indicates that three

flat panel display technologies presently show great promise: electroluminescence (EL), light emitting diodes (LED), and liquid crystal (LC). Others that have not yet reached the development stage but are to be seriously considered and discussed are plasma, electrochromic, electrophoretic, ferroelectric, magnetic particle, and microchannel plate display technologies.

Thin Film Electroluminiscent (TFEL). TFEL devices have solid-state, thin-film structure consisting of a ZnS phosphor layer deposit with Mn sandwiched between two insulating layers of high-quality dielectric glass sheets that serve as the substrate for deposition and sealing of the TFEL structure. This display structure is nearly transparent, a quality that could be advantageous for TFEL interface with other display materials such as maps.

The discrimination ratio between the sharpness of the brightness vs voltage curve for TFEL is very high (10^4-10^5). This characteristic has allowed the multiplexing of hundreds of lines in a matrix display by a simple crossed-grid approach and has enabled this technology to become a highly useful graph and video display tool (ref 33).

Existing TFEL displays are light in weight. Operating lifetime has been reported in excess of 30 000 hours. A commercially available 240 x 320 pixel graphics terminal weighs 2 pounds complete (ref 33).

Light Emitting Diode (LED). LED technology is based on a principle called carrier injection electroluminescence. Light is produced when loosely bound electrons on the n-doped side of a pn junction are injected across the diode junction region and combine with majority carrier holes. Success has been achieved in producing light emitting diode junctions in solid-state compounds from elements of groups III and V in the periodic table, including GaP, GaAsP, and GaInP.

The primary LED development thrust for use in military aircraft displays has been in GaP monolithic chip arrays suitable for forming the mosaic surfaces of dot-matrix display modules. Quarter-inch-square 64-picture-elements (pixel)/inch monolithic chips have been successfully demonstrated. Further development effort is still required to produce a chip with a resolution compatible to that of current CRT displays (126 pixel/inch), used by aircraft for the portrayal of video information.

Large display surface constructions from standard modular LED chips offer several advantages over CRTs, including the capability of being configured in various sizes and shapes for various requirements and the interchangeability of modules, resulting in reduced logistics inventory requirements. A disadvantage associated with modular display construction is that a very tight mechanical tolerance requirement must be achieved to provide intermodule alignments suitable for a unified display appearance.

Liquid Crystal (LC). LC displays are being developed as an alternative to the CRT. Their advantages include high contrast over large and small areas

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33. Allan, R, Flat-Panel Displays Find Special Jobs, Electronics, vol 53, no 3, p 67-68, 31 January 1980.

under all levels of illumination, uniformly high resolution over the entire display surface, simple interface, and low weight, power, and volume (ref 34).

A liquid crystal display, unlike a CRT, is nonemissive, ie it does not produce any light itself. Natural or artificial illumination is required. Contrast is produced by control of the diffuse reflection of ambient light. LC displays modulate light by means of scattering, birefringence, polarization, absorption, or a combination of various optical effects. Dynamic scattering and twisted nematic are the two most commonly used modes of operation (ref 32).

LC displays operate at low voltages (2 to 20 volts). Thus they are compatible with any form of semiconductor drive circuitry and they have low power consumption, typically in the neighborhood of 0.05 to 0.5 microwatt per pixel. Because they are nonemissive, contrast increases with increased ambient lighting. Thus good visibility (typically 8-10 shades of gray) is attainable in direct sunlight. Test data analyses also indicate high reliability and long (10 000-hour) lifetime (ref 32).

DOD efforts have concentrated on the development of video displays to present sensor and symbolic imagery such as graphics and alphanumerics. The state of the art of these developments is represented by a 0.8 by 1.0 inch LC display with 240 by 320 (76 800) picture elements, which can display a TV image.

Hard-Copy Displays

The two types of video hard-copy devices used in a number of undersea search related applications are the electrostatic recorder and the electro-optic recorder. Electrostatic recorders produce high-resolution line-scan recordings and are used in a number of search related applications, including sonar recordings, spectral data analysis printout, multispectral data printout, and bottom profiling. A standard unit is capable of writing about 100 line pairs per inch on 19-inch-wide paper with a horizontal resolution of about 4000 data points per sweep. The sweep speed ranges anywhere from 1/4 to 2 seconds, or wider if necessary, with no dead time.

The recordings are usually made on white dry electrostatic paper capable of a dynamic recording range of over 23 dB. Basically, the units consist of accurately controlled stylus and paper-drive systems. The intensity of the mark is the electrical current supplied to the stylus. When the stylus voltage reaches a certain threshold level, the paper resistance drops off rapidly and the intensity of the marking then becomes a function of voltage, current drive, and stylus (paper) speed.

Electro-optic recorders are also line-scan devices with very high resolution that exceeds 350 line pairs per inch. Imaging is achieved by recording the light intensity from the electron beam output of either a line-scanned fiber optic or cathode-ray tube on a dry photosensitive paper.

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34. Ernstoff, MN, Liquid Crystal Pictorial Display, Hughes Corp paper presented at SID Technical Meeting, Culver City CA, 6 November 1975.

The writing resolution is more than twice that which can be obtained from a mechanical stylus recorder. The gray-scale dynamic range is reported to be greater than 20 dB. The inherent resolution capability of each recorder is usually determined by and designed for its specific application. A typical resolution may range between 0.005 and 0.002 inch spot size. Some of the search related applications are sonar imagery, television imagery, infrared imagery, bottom contouring, spectrum analysis, and graphic records of computer analyzed information.

GRAPHIC DISPLAY DEVICES

Raster-Scan Displays

Until recently, the graphics market has been dominated by storage tubes and calligraphic (stroke-writing) displays. With the advent of lower priced memory, we see an increase in the influx of raster-scan displays.

The raster-scan display principle is the same as that used by commercial television. The image is produced on the screen by varying the intensity of a beam as it periodically scans from side to side along a fixed number of scan lines, from the top to the bottom of the tube.

The state of the art in video graphic display resolution with raster-scan displays is about 1024 by 1024 picture elements (pixels). On raster-scan displays, each dot on the screen is displayed 30 times each second. Each pixel is stored in a memory buffer location, and the buffer is used as the refresh memory for the screen. The need for refreshing is the major reason for the large memory requirements of this type of display system.

There are two usual ways to display color. In one method, the bits for each pixel are divided among three primary colors (red, blue, and green). In the second method, a color map is used. A color map is basically a color look-up table that takes the value of each stored pixel and outputs the individual assigned intensities to each electron gun. The number of colors than can be displayed is a product of the number of output intensities for each color (ie, 8 bits can display 256 colors).

The following are some of the vendors that provide interactive computer graphic systems for raster refresh displays: Applicom, Inc (AGS); Calma Corp; Chromatics, Inc; Comtal Corp (Vision One/20); DeAnza Systems, Inc (VISCOM); General Electric Corp (Genigraphic); Hewlett Packard Co (HP-2647A); Ramtek Corp (RM series); Three Rivers Computer Corp (Perq); and Apple Computer, Inc (Apple III Plus).

Vector Displays

There are two types of vector graphic (line-drawing) systems: the directed beam refresh (refresh calligraphic writer) and direct-view storage tube (DVST). In the directed-beam displays, the beam is moved from point to point on the screen to produce the desired image rather than being scanned periodically. The image is maintained on the screen by being redrawn completely at a periodic refresh rate. The state of the art in upper limits

for this type of display is about 20 000 three-dimensional or 100 000 two-dimensional vectors at a frame rate of 30 per second.

The following are some of the vendors that provide interactive computer graphic systems for vector refresh displays: Evans and Sutherland (Picture Systems II); Emlac Corp (PDS-1, PDS-4, and dynagraphic series); Information Displays, Inc (System 150); Vector General, Inc (Series 3, 8300, and 8400); and Megatek Corp (Wizzard Series).

In direct-view storage displays, the image-drawing method (vector drawing) is the same as that used by the direct-beam display. The difference is that the image is stored in the phosphor of the CRT screen, so that periodic refresh is not necessary. The storage tubes available today have very high resolution and produce good image quality. The major disadvantage of this type of display system is that it lacks the capability of selective erase. To remove one segment of line, the entire screen has to be erased and redrawn.

The following are some of the vendors that provide interactive computer graphics systems for direct-view storage displays: Applicom, Inc (AGS Series); Comarc Designer Systems; Gerber Systems Technology, Inc (IDC-80); McAuto (Unigraphics); Summagraphic Corp (Datagrid II); Synercom Technology, Inc.; and Tektronics, Inc (Model 4051, 4052, and 4054).

Calligraphic CRTs use either beam-penetration or shadow-mask technology to produce color. In beam-penetration displays, the screen is coated with two layers of different-colored phosphor (green and red). The color produced is dependent on the penetration (strength) of the electron beam through these layers of phosphor. The color range of such devices is very limited.

Shadow-mark displays work much like ordinary color television tubes. The inner surface of the CRT screen is coated with a fine matrix of red, green, and blue phosphor dots. Three electron guns are used to excite the associated dots through tiny holes in a "shadow mask," which serves to block certain beams. These types of displays do not draw lines as sharp as those produced by the beam-penetration type but they have the advantage of being able to generate many more colors.

Hard-Copy Devices

There are many different types of hard-copy devices available in today's graphics market. The most common type is the pen plotter, whose range of price may vary anywhere from $1000 to $100 000, depending on its size (8-1/2 by 11 inches or larger), speed of 1 to 50 inches per second), resolution (0.01 to 0.0005 inch), number of pens (1 or more), tablet type (drum, flatbed, or others), etc (ref 35). The pen plotter is the most extensively used hard-copy device in today's search systems. Its main application is in the area of navigation (Deep Tow, ANGUS, Trieste II, and RUWS).

35. Orr, J, Interactive Computer Graphics Systems, Mini-Micro Systems, p 68-78, December 1979.

The following are other available hard-copy devices: Electrostatic plotters (Edo Western 550A, 555A, 614); electro-optical recorders (Tektronics 431 and Edo Western Fiber Optic Records); thermal plotters (Hewlett-Packard 7240A, 7242B, and 7310A); and color copiers (Xerox 6500).

MESSAGE DISPLAY DEVICES

The function of the display system, again, is to provide the interface between the human operator and the search system. Thus far in our characterization of display devices, we have been concerned mostly with the output of data from the system to the human operator. Also vital to any communication network, however, is the input of information to the system. Therefore, we are faced with the task of selecting a data terminal, often defined as a point at which information can enter or leave a network or as any input/output device capable of sending and receiving data.

There are three broad classifications for the terminal devices available in today's market; dumb, smart, and intelligent. These terms are not necessarily forms of endearment or mockery, but merely descriptions of the different levels of functional ability. Dumb terminals are those that have the basic capabilities of a teletypewriter. Smart terminals are those that are usually microprocessor-based but not capable of providing the user with program ability. They have functions such as editing, block data transmission, and information update. Intelligent terminals are programmable devices having internal memory that enables the operator to develop software.

CRT Terminals

CRT terminals have been in the market since 1965, when IBM first introduced the device to the world (ref 36) as Model 2260, which was part of the IBM System/360. By today's standards, this device would be classified as dumb.

The most common CRT screen size found in today's market is one that can display 24 lines of 132 characters. The price range for CRT terminals varies from about $800 for a dumb terminal to a high of about $4000 for an intelligent one. Overall, there are about 90 vendors offering nearly 300 terminal models (ref 36).

LED Terminals

LED technology offers increases in intelligence, efficiency, and power handling capability, as well as a broad array of color selection.

The state of the art in LED development centers on products made either with gallium phosphide or with gallium arsenide on gallium phosphide. These materials produce an LED device of higher efficiency than the first-generation gallium arsenide phosphide devices. Their increased brightness level, higher reliability, and longer life has caused their ability as light sources to be

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36. Lusa, JM, Infosystems Report: Terminal Alternatives, Infosystems, vol 27, no 5, part 1, p 45-54, May 1980.

compared to incandescent lights (ref 37). Development in LED technology is making it possible to pack LED chips closer together, for use in forming multisegmented displays.

The concept of an intelligent display was introduced in 1977 by Litronix, Inc, Cupertino, California (ref 37). Their first device was a 4-digit 16-segment alphanumeric chip with characters 1/4 inch high and associated interface circuitry. Today's state of the art in LED displays under microprocessor control can be represented by the Hewlett-Packard HDSP-24xx series, utilizing the HDSP-2000 display. Its features include a 5 by 5 dot matrix, up to 128 characters and 40 elements, multiple data entry (left, right, RAM block), and editing features (cursor, backspace, forward space, insert, delete, and clear). Each character position is addressable by either hardware or software command (HP Opto-electronic catalog, 1980).

The following are companies that offer intelligent LED assembles: Litronix, Inc, Cupertino, CA; Texas Instruments, Inc, Dallas, TX; Industrial Electronic Engineers, Inc, Van Nuys, CA; Plessey Opto-electronics, Irvine, CA; and Opcao, Inc, Edwin, NJ.

LCD Terminals

The unique operating characteristic of LCDs make it advantageous for display application in the following areas: outdoor or high ambient-light applications where LCDs have an advantage of readability over other types of incandescent displays; low-power applications, where the LCD's microwatt designation makes it ideal for portable instrument applications; and high-information-density applications, where resolution of 100 lines or more per inch can be obtained easily by present LCD technology. The disadvantages of LCD displays include the expense of building large-area displays and the facts that LCDs are temperature sensitive and have a slow response (ref 37).

Some of the firms that make and supply LCDs are as follows: Hamlin, Inc, Lake Mills, WI; Beckman Instruments, Inc, Fullerton, CA; National Semiconductor Corp, Santa Clara, CA; and UCE, Inc, Norwalk, CA.

The Japanese are also involved in LCD panel development. Matsushita Electric Industrial Co, Ltd, of Osaka; Seiko Denki Corp, Ltd, of Tokyo; and Hitachi Ltd, of Tokyo, have all demonstrated LCD panels for portable TVs. Matsushita developed a 1.4 by 1.9 inch panel with 240 by 240 picture elements, and Hitachi has shown a 3-inch diagonal panel with 240 by 380 picture elements (ref 33).

Plasma Panels

Ac plasma devices usually use a neon-argon gas mixture enclosed between dielectric coated conductors to produce an orange glow when the proper voltages are applied. A resolution of 50 to 60 pixels per inch has been achieved. An ac plasma panel is a bistable device, therefore does not require a refresh memory as do CRTs.

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37. Allan, R, Display Technologies Offer Rich Lode for Designers, Electronics, vol 53, no 6, p 127-138, 13 March 1980.

The dc version of the plasma panel differs from the ac version in that the electrodes are not separated from the base mixture by a dielectric layer but are in direct contact with it. Because the dc panel is structured differently, it does not have the inherent memory capability of the ac panel. The advantage gained is a full range of gray-scale capability not found in the ac panel. Both types of panels are used extensively for alphanumeric terminal applications.

Companies in the ac plasma panel business are IBM Corp, White Plains, NY; CDC Corp, St Paul, MN; Norden Division of United Aircraft Corp, Norwald, CT; NCR Co, Colorado Springs, CO; Nippon Electric Co, Tokyo, Japan; Fuhitsu, Ltd, Tokyo, Japan; Texas Instruments, Inc, Dallas, TX; Honeywell, Tampa, Fl; Photonics Technology, Inc, Luckey, OH; Electro-Plasma, Inc, Millbury, OH; and Burroughs Corp, Plainfield, NJ.

The largest ac plasma panel built is a 24-inch diagonal unit with 1024 by 1024 addressable elements and a resolution of 60 pixels per inch, capable of displaying over 21 000 characters. This unit was built for the military by Photonic Technology and Science Applications, Inc, La Jolla, CA (ref 37).

Thin-Film Electroluminescent Panels

In a study sponsored by the Office of Undersecretary of Defense for Research and Engineering (ref 32), it was reported that of all the display technologies that are competing in large flat panels as possible replacements for the CRT, the ac TFEL panels appear to be the most promising primarily because of the simplicity of the thin-film process compared to the other flat-panel technologies. This enables the development of low-cost large-area flat panels capable of competing with the CRT. The additional advantages of the ac TFEL panel are its ability to operate over a wide ambient temperature range and its low power requirement, high luminous efficiency, and rugged nature.

Most of the development effort is presently centered in the area of research to perfect the ac TFEL displays. Only one company thus far has marketed a product, a 320 by 240 element panel with a 10-year lifetime, offered by Sharp Corporation of Japan through its Irvine, CA office (ref 37).

3 PROCESSING FUNCTION

The search sensor operator is faced with the problem of detecting a signal emanating from a target. In a sonar system, the signal may be an echo from a transmitted signal or it may be generated by the source itself. These two modes are commonly distinguished as active and passive, respectively. In a visual search system (TV or photographic), the signal may be a reflection of the light rays from an object below the surface.

The term "detection" is used here when the question to be answered is, "Is any signal or target present?" The search system provides the answer by either a deterministic or a probabilistic process. Usually the system provides only one of two answers: "Yes, a signal is present," or "No, a signal is not present."

Frequently it is desirable to determine along with the presence or absence of a signal one or more parameters associated with the signal, in a function usually referred to as target classification. Associated parameters may vary widely from simple quantitative time of arrival, target bearing, and signal strength to complete recovery of the waveform. The process of recovering parameters is often referred to as signal processing.

The domain of signal processing is broad. A review of all aspects related to the subject of signal processing relevant to underwater search is beyond the scope of this document, the emphasis of which is directed particularly to image processing (ref 2, p 24-26, in keeping with the AUSS program plan). The term "imaging" herein usually applies to optical imaging, although in most cases the techniques are applicable to acoustic imaging, especially in the existing side-looking and scanning-type sonar systems.

The discussion centers around the relationship of image processing to the search functions of underwater target detection, classification, and identification. A human operator is assumed to be performing these functions. The objective is to bring to light processing techniques that can improve image quality from a human perceptual aspect, thus enhancing the search function.

This section discusses first techniques, then hardware. Under techniques is covered relevant search-related image processing (image enhancement and analysis). Under hardware are covered both dedicated stand-alone units and minicomputer systems.

Image processing is an important aspect of search-related signal processing. In a data handling system, display and processing are nonseparable functions. In performing detection, classification, and identification functions, display and processing requirements become nonindependent if not equivalent (ie it becomes difficult to determine which functional requirement dictates the other).

The two main-stream technology areas of image processing are image enhancement (for detection and classification) and image analysis (for classification and identification).

IMAGE ENHANCEMENT TECHNIQUES

Image enhancement, for search-related applications, means in its most general sense that which is done to the image (input) to produce a detectable signal output. The process may range from a simple one-bit system (yes or no) to a more complex system using many more bits to characterize image quality. The image enhancement (detection) process definition herein is limited to apply only to the processing done to the image itself. It involves producing numerical parameters from the input image, then applying a decision network (algorithm) to generate desired enhancement effects to aid the operator in detecting the target. Image enhancement operations either improve the appearance of an image to a human viewer or convert an image to a format better suited for human or machine analysis of sensor output information for the purpose of detecting and classifying targets.

At present there is no generally agreed-upon standard of image quality that can serve as a design criterion for the underwater search process (detection, classification, and identification). A variety of techniques discussed in section 2, Display Function, have proven to be useful from human perception and machine analysis aspects in improving the search function. In image processing for visual interpretation, the operator (viewer) determines how well the particular method works. Visual evaluation of image quality is a highly subjective process. Generalization from assessment results obtained from the laboratory cannot be done with complete confidence (ref 5). The definition of image quality can be very elusive when enhancement techniques and algorithms are being assessed. On the other hand, the evaluation of image processing for machine perception is somewhat easier. For machine processing, the end results desired must be predefined. Thus the best image processing method is the one that yields the best machine results.

Contrast Ratio

Poor contrast ratio is a major problem in undersea imagery systems. Seawater has a very complex effect on light and sound transmission. In a report on underwater image system design (ref 38), these problems are attributed to three basic physical properties: attenuation, backscatter, and small-angle forward scattering. Attenuation of light in water is a function of wavelength (color). In clear water, minimum attenuation of visible light occurs near the 4800 Å or blue-green region. The propagation of light in water is severely limited. Light is attenuated exponentially with range. Even with the latest and most sensitive optical imaging systems, the maximum distance of view in clear ocean water is only a few hundred metres. In turbid water, visibility can be limited to only a few feet.

Scattering is the process by which the direction of individual photons is changed by the medium. Most scattering of light in seawater is caused by suspended particles of various sizes. Scattering is nearly independent of wavelength.

Backscatter occurs when the light source is scattered into the receiver's (camera's) field of view by particles and inhomogeneities in water. This phenomenon has the effect of degrading the image contrast to the point where it greatly hampers the ability to detect or recognize features and targets.

Small-angle forward scattering is scattering caused by the refractive deviation of light passing through transparent plankton and by temperature and salinity fluctuations.

The effect of backscatter can be reduced in conventional imaging systems by using large source-receiver separation and source and receivers with narrow-beam field of view (ref 38).

Current underwater search systems employ the technique of displacing the lumination (light) source from the optical sensors (TV and photographic

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38. NOSC Technical Report NUC TP 303, Handbook of Underwater Imaging System Design, by CJ Funk, SB Bryant, and PJ Heckman Jr, July 1972.

cameras) to reduce the effect of backscatter interference. In the Scripps Oceanographic Institute Deep Tow search system, for example, the light source is displaced vertically from the sensors by suspending it about 40 feet below the vehicle. The basic design goals were to provide maximum illumination within a minimum volume of light-filled water and to mask backscattered light (ref 39). In the Woods Hole Oceanographic Institute Acoustic Navigation Geological Undersea System (ANGUS) search system, the light source and camera are displaced horizontally. The basic operational configuration consists of the 35 mm photographic cameras mounted at the forward end and the 1500 W light strobes mounted about 14 feet away at the aft end of the vehicle.

In sonar systems, a portion of the total acoustic energy at the receiver may be a signal, the remainder the background. The background is either reverberation (the decaying portion of the background representing the return of one's own acoustic output by scatterers in the sea) or noise (all other portions not due to the echo ranging from the target).

Improving Contrast Ratio by Intensity Rescaling

A powerful means of improving or enhancing contrast within an image is to rescale the sensor data values for each discrete picture element (pixel) of the displayed image (ref 40, p 3).

Two common methods used to perform intensity rescaling are linear and nonlinear mapping (ref 40-42). Reference 40 points out that piecewise linear and nonlinear mapping are at times advantageous because a relatively small range of high-interest data values in an original image can be rescaled easily to a relatively large portion of the displayed pixel intensity dynamic range.

Improving Contrast Ratio by Histogram Modification

In most natural images, details in the darker regions often are not very perceptible because the distribution of the pixel values (intensity) is usually skewed toward the darker or lower levels. Rescaling by means of histogram modification techniques often will improve the visual perception of detail within the image. One very effective technique of histogram modification is called histogram equalization (ref 40, 43). The process of

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39. Scripps Institution of Oceanography Report, Marine Physical Laboratory Deep Tow Instrumentation System, by FN Spiess and RC Tyce, Marine Physical Laboratory, San Diego CA, 1 March 1973.

40. NOSC TR 439, Processing and Display Techniques for Multispectral Satellite Imagery, by JA Roese, April 1979.

41. Pratt, WK, Digital Image Processing, John Wiley and Sons, Inc, New York NY, 1978.

42. Rosenfeld, A, and AC Kak, Digital Picture Processing, Academic Press, Inc, New York NY, 1976.

43. Gonzalez, RC, and P Wintz, Digital Image Processing, Addison-Wesley Publishing Company, Reading MA, 1977.

histogram equalization is a linear rescaling of the histogram of the enhanced image to make it approximately uniform.

Edge Enhancement

Human perceptual experiments indicate that an image (photograph, video signal) with accentuated edges is very often more pleasing than an exact reproduction (ref 41).

Edge enhancement (sharpening or crispening) can be achieved in many different ways. For images that are scanned electronically, there are electrical filters with a high-frequency passband or a technique called unsharp marking. The subjective edge enhancement of the image is obtained in this process by scanning the image with two overlapping apertures, one at normal resolution and the other at low resolution, eventually forming a masked signal with enhanced edge gradients (ref 44, 41).

Differentiation of pixels over a region will have the effect of sharpening the image. The most commonly used method of differentiation in image processing applications is gradient approximation. Two specific types of this commonly used technique are the Roberts and Sobel gradient operations, which will be discussed in more detail later.

The effects of derivative operators in sharpening pictures can also be interpreted from a spatial frequency domain. Since the derivative of sin nx is n cos nx, the higher the spatial frequency of a sinusoidal pattern, the higher the amplitude of its derivative. Thus edges are associated with high-frequency components, and sharpening can also be achieved in the frequency domain by high-pass filtering.

Color

A relatively new and potentially powerful technique of digital image processing is the use of color for image display and enhancement. It has been determined through psychophysical experiments that human perception capability is greatly enhanced by color. It is reasoned that humans can discriminate color more easily than intensity.

Pseudocolor. Pseudocolor is a color mapping technique designed to enhance the ability of a human observer to detect objects within an image. The original image is a two-dimensional array of monochrome values that is converted to the color plane. The objective is to assign a color to each pixel on the basis of some value or parameter (eg its intensity). The range of techniques for color assignment is limited only by the capabilities of the display system.

The density (an intensity) slicing technique of color coding is one of the simplest examples of pseudocolor image processing (ref 43). It can be viewed as one of placing color separating planes that "slice" the density or

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44. Schreiber, WF, Wirephoto Quality Improvement by Unsharp Masking, J Pattern Recognition, vol 2, Pergamon Press, London, 1970.

intensity function of an image. Colors are assigned to show pixel intensities within certain ranges of values.

There are other more general types of gray-level to color transforms capable of achieving a wider range of pseudocolor enhancement results. One very popular approach is to perform three independent transforms on the gray levels of any input pixel. The three results are then fed into three (red, green, and blue) separate guns of a television monitor. The result is a composite image whose color is modulated by the transform function. In most commercially available display/processor units, the transform function is implemented in the form of a look-up table, for simplicity and speed.

There are also color coding schemes based on frequency-domain operation (ref 20, 40). An example of one technique is to color-code the regions of an image on the basis of frequency or perhaps amplitude (gray level). A typical filtering approach is to use low-pass, high-pass, band-pass, or band-reject filters to obtain the three primary color components.

Color in Sonar Displays. Initial studies (ref 45, 46) conducted with color systems indicated that certain color schemes used to display passive sonar information enhance the visibility of the signal in background noise when color is encoded in gray-scale gradations.

Reference 47, a summary of a study by Tracor Inc to assess the use of color as a sonar display parameter, reports that by coding light levels of intensity in a gray scale and comparing that as a baseline with a carefully selected set of eight colors, an effective gain in signal detectability is obtained with color. The study concludes that color coding enhances perceptibility by increasing the amount of usable information available to the observer—ie by increasing the number of perceptual elements and the ability to discriminate.

In a study to compare the relative perceptibility of acoustic signal patterns between black-and-white and color displays (ref 20), color displays were shown to be superior for perceiving patterning, contouring, and equivalent amplitudes. And for discriminating patterns of very weak signals in noise, color displays are equivalent to gray-scale displays. The study centered around determining the effect of using 8 to 64 discriminating levels of both gray-scale and color coding on an acoustic image.

The performance of an observer in searching for specific information can be enhanced by selectively presenting different types or categories of infor-

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45. Tracor Document, Engineering Guidelines for the Use of Color in a Sonar Display, by WB Butler and WM McKemie, Tracor, Inc, Austin TX, 25 February 1971.

46. Tracor Document T71-AU-9521-U, Color and Black and White Display of Sonar Information, by WB Butler, Tracor Inc, Austin TX, 25 February 1971.

47. Tracor Document, Summary Report on the Assessment of Color as a Sonar Display Parameter: Extension of the Dynamic Range of Color, Tracor Inc, Austin TX, November 1968, AD844927.

mation in perceptually distinctive colors. Much research has been dedicated to this topic, but quantitative criteria assessments for determining and evaluating color coding are essentially nonexistent.

Limitations to our knowledge of quantitative color coding utility and criteria as indicated by reference 48 stem from (1) lack of rigorous quantitative measurement standards and understanding of the nature of the chromatic stimuli in most experiments, and (2) some adaptive, nonlinear characteristics of the visual system which lead to situation-specific conclusions only.

The value of color coding is dependent on its specific application (ref 49). It can be beneficial, neutral, or distracting.

IMAGE ANALYSIS TECHNIQUES

Image analysis, another major division of image processing, deals with extracting data, measurements, and other useful or descriptive information from an image by either automatic or semiautomatic (interactive) devices or systems.

Image analysis differs from image enhancement in that the ultimate goal of the image analysis system is a descriptive or numerical output rather than another image or picture. In the literature, this area of image processing may also be referred to as image data extraction, image understanding, scene analysis, image description, pattern recognition, etc.

To generate a description of an image it is necessary to segment the image into specific parts, regions, objects, or feature vectors. Segmentation refers to the process of partitioning the image field into regions that are meaningful with respect to the classification and identification functions of underwater search. For example, in an image derived from viewing a three-dimensional scene of the ocean bottom, the objective of segmentation might be to identify regions corresponding to objects in the scene. In ocean bottom search applications, such regions could correspond to man-made objects, natural terrain, rocks, and sandy or mud bottom.

Amplitude Segmentation

The measure of image amplitude in terms of spectrum, luminance, etc is probably the most basic of all image features. Amplitude may be measured at specific points or over neighborhoods of the image. Image amplitude measurements could be of major importance in the isolation and eventual classification of objects within an image field. An example of the average luminance of a (2N + 1) by (2N + 1) pixel neighborhood is given by reference 41:

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48. Virginia Polytechnic Institute and State University Report, Human Visual Performance and Flat Panel Display Image Quality, by HL Snyder, Blackburg VA, July 1980.

49. Honeywell Report ONR-CR213-136-2F, Color Display Design Guide, by MJ Krebs, JD Wolf, and JH Sandrig, Minneapolis MN, October 1978.

$$A(j,k) = \frac{1}{(2N + 1)^2} \sum_{M=-N}^{N} \sum_{n=-w}^{N} A(j + m, k + n) .$$

Amplitude (Gray-Level) Thresholding

Many images (sonar or television) can be characterized as containing some objects of interest of reasonably uniform brightness placed against a background of differing brightness. An example could be a mine or torpedo lying on a flat muddy or sandy bottom. Brightness of the images generated by either the sonar or television would be very distinguishable and commonly would serve for object detection and identification. If the image of the target of interest were high in amplitude (white) against a low amplitude (black) background, or vice versa, then it would be trivial to define threshold to bound and locate the object. In reality, however, the observed image is usually obscured in noise and assumes a broad-range gray scale. The background is also very frequently not homogeneous. There are many available approaches to and techniques of luminance thresholding. Discussions and recommendations are presented in more detail by references 41-43.

The alternative to segmenting an image of similar characteristics on the basis of point properties (ie amplitude) is to segment on the basis of regional properties. This technique could greatly enhance the dimensionality of the feature vectors used for making classification or even identification decisions. An example is the boundary (edge, line, texture, etc) determination process. An edge may define regions of different characteristics. A line may be defined as a pair of edges with a common characteristic between them. A region may be a closed area bounded by edges and lines. Texture may be used as an overall or global representation of the differences in gray-level content over a local region. Differences in texture may be used to identify or classify different local regions.

Template Matching

One of the most fundamental means of object detection or classification within an image field is template matching. This concept has found wide acceptance in segmentation applications because of its simplicity (ref 43). It works by comparing the image of an object (or its edge picture) with stored images (templates, outlines, masks, or windows) of known objects. The template with the highest correlation is selected as the result (ref 50). Discussions on template matching techniques are presented in further detail by references 41-43 and 51-53.

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50. Thompson, AM, Introduction to Robotic Vision, Robotic Age, vol 1, no 2, p 22-34, Summer 1979.

51. Rosenfeld, A, Image Pattern Recognition, Proceedings of the IEEE, vol 69, no 5, p 590-605, May 1981.

52. Duda, RO, and PE Hart, Pattern Classification and Scene Analysis, John Wiley & Sons, New York, 1973.

53. Lindsay, PH, and DA Norman, Human Information Processing, Academic Press, Inc, New York, 1972.

Edge Detection

One of the very first steps in image analysis is to locate areas in the image that correspond to part of the object or its whole. This process involves isolating the image of each object from the background. In many environments, however, this is not always possible. A common tool used to find objects is edge detection, a technique that attempts to locate the boundaries of objects or regions in the image. Boundary locations, sizes, and shapes may serve as clues for classification and recognition.

The detection of edges or boundaries representing intensity transitions is a common form of analysis of remotely sensed imagery. Edge detection is based on the assumption that there is a difference in brightness (contrast) between object and background.

Once the image is represented in digital form as a two-dimensional array (pixel) of gray levels, the edge detection process can begin. Edges are located in the array by applying an operator that looks for high contrast areas within the digitized images. The operator usually examines a small set of adjacent pixels and computes an "edge probability" value. If the computed probability is above a certain threshold value, a flag is set to signify the presence of an edge at the appropriate spot in the image.

The size of the set of adjacent pixels (window) used to compute the edge determines the sensitivity of the window to noise. Each pixel is subject to numerous noise sources that can cause error. Noise can stem from environment effects on the sensor image transmission process, or it can be the produced in the image electronic transduction process between the sensor and the edge-detection processor. Regardless, the presence of noise can lead to the detection of false edges. To avoid this problem and reduce the effect of noise, an averaging scheme can be employed. Averaging over a large window is more accurate in that it reduces the effect of noise and often is capable of detecting fuzzy edges that a smaller window might miss. But if the window is too large, the requirement for increased processing greatly reduces the speed. A tradeoff must be made between the reliability of the edge detector and its speed (ref 50).

A frequently used class of image detectors is based on nonlinear combination of intensity values in adjacent sets of four or nine pixels. Reference 40 reviews two typical edge detection techniques, the Roberts cross operator for a 2 by 2 region on an image and the Sobel gradient operator for a 3 by 3 region on an image. The Roberts cross operator is basically a two-dimensional differencing technique defined as follows:

$$R_{SR}(x,y) = \Big\{[I(x, y) - I(x + 1, y + 1)]^2 + [I(x, y + 1) - I(x + 1, y)]^2\Big\}^{1/2} ,$$

where $I(x, y)$ is the pixel intensity value of the image at location x, y, and $R_{SR}(x, y)$ is the edge detection measure.

The Sobel gradient is an extension of the four-element (2 by 2) technique to a nine-element (3 by 3) pixel subset. Given that the image is represented as a pixel array (ref 50), let the 3 by 3 window centered around one pixel be represented by the following matrix:

A	B	C
D	E	F
G	H	I

Then the "edge value" at pixel E is computed by the formula

$$\mathrm{edge}(E) = \{[(A + 2B + C)(G + 2H + I)]^2 + [(A + 2D + G)(C + 2F + I)]^2\}^{1/2} ,$$

where each letter represents the intensity or gray-scale level of the pixel.

Both the Roberts and Sobel edge detection functions have the advantage of being relatively fast, although the small sampling window (3 by 3) makes them very sensitive to noise and less sensitive to fuzzy edges. These techniques have been used in satellite image analysis for isolating strong or weak edge structures within an image (ref 40).

Reference 50 reports that the Sobel gradient operator is easily implemented in software by further simplifying to the approximation

$$(a^2 + b^2)^{1/2} \approx a + b .$$

Because this approximation offers the simplicity of summing the absolute values of the alternate difference, thus avoiding multiplications and square roots, digital hardware can be used to produce real-time edge pictures. The JPL Robotics Project uses such a hardware implementation, which allows a robotic vehicle to track moving edges in real time.

Clustering

Clustering refers to a process of collecting clusters of adjacent pixels that have similar properties. The process of pixel clustering is conducted by a discrimination function that computes and compares the desired property with a threshold or computed value from other pixels in the region. An example of a simple clustering discrimination scheme is the process used by many industrial robotic systems to locate objects by looking for regions whose gray-scale level is above (or below) that of the background. More complex clustering schemes exist as functions comparable to edge detectors that compute the property from the adjacent pixels, starting from a "seed" pixel and expanding to the boundaries (ref 50).

Since clustering has the advantage that the boundary of the region is closed, it can be used to compute properties dependent upon shape, such as various integral or statistical moments, etc (ref 50).

IMAGE PROCESSING HARDWARE AND SOFTWARE

Several companies (COMTEL, Aydin, International Imaging Systems) produce complete image processing and analysis work stations. Many offer specialized image processing hardware units that can be easily integrated into already existing computer systems. The basic image processing system generally includes a raster-type CRT image display device, an alphanumeric terminal, magnetic storage units, a minicomputer, and special-purpose image processing hardware units.

Software has always been one of the major problems in the field of image processing. One analysis of software requirements to support image processing (ref 54) defines the following as the major elements of an image processing software system:

Processing mode
Command format
Image file structure
Application packages
Numerical computation package

Processing Mode Software

The three major modes of processing are batch, interactive time share, and hybrid batch/interactive. A time-sharing system is ideal during system (program) development. Batch processing is essential during operation.

Command Format Software

The three basic modes of command format are question and answer, menu, and command strings. The menu format is well suited for an operational system such as might be found on a shipboard support system for an underwater search vehicle. Quickest is the interactive format, but it places the greatest burden on the operator.

Image File Software

An image file is an array of the image data (pixel values). Most files would include the following:

Header of physical file information

- Image size specification
  - Number of rows
  - Number of columns
  - Spectral information

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54. Pratt, WK, 411 Digital Image Analysis and Understanding: The State of the Art, Course Notes, Integrated Computer Systems, Inc, Santa Monica CA, 1981.

Access specification
  Size of processing block

Mode specification
  Byte length
  Byte type: integer, real, complex

Other information
  Min/max pixel value
  Mean value

History records

User information
  Image origin
  Digitalization method
  Accession number
  Other

Processor information
  Input/output file name
  Processes invoked
  Process parameters

Statistical information
  Input/output histogram
  Means
  Covariances
  Entropy

Application Package Software

The following is a list of image processing software application packages considered by reference 54 to be among the most important for a generalized image processing system:

Arithmetic
  Add/subtract
  Multiply
  Ratio
  Maximum/minimum

Statistical
  Histogram
  Moments
  Covariance
  Entropy

Point operations
  Linear/log
  Root
  Histogram modification
  Pseudocolor

Neighborhood operations
- Average
- Laplacian
- Edge sharpening
- Median filter

Transform
- Fourier
- Cosine
- Hadamard
- Karhunen-Loeve
- SVD

Fourier filters
- Low-pass
- High-pass
- Windowing
- Block mode

Geometric
- Insertion/extraction
- Interpolation
- Warping

Numerical Computation Package Software

The most widely used packages of numerical computation programs are the IBM scientific subroutine packs, the IMSL package, and the EISPAK and FUNPAK distributed by Argonne National Laboratory (ref 54). Other image processing software systems include the following:

CHAP	Rensselaer Polytechnic Institute (chain code processing for CDC-7600)
IDIMS	Electromagnetic Sensing Laboratory (image processing work station software for an HP-3000 system)
KANDIDATS	University of Kansas (multispectral image processing)
LADIES	Los Alamos Scientific Laboratory (general software collection for CDC-7600)
PAX	University of Maryland (obsolete software developed for ILLIAC III)
SCIMPL	University of Southern California (general software collection for PDP-10)
VICAR	Jet Propulsion Laboratory (production software for IBM 370)

XAP University of Maryland
(general software collection for UNIVAC)

STAND-ALONE PROCESSING HARDWARE VENDORS

The following vendors are among those that provide various stand-alone and supporting image processing systems:

Aydin Controls
414 Commerce Drive
Fort Washington, PA 19034
(215) 542-7800

Compression Labs, Inc
10440 N Tantan Avenue
Cupertino, CA 95014
(408) 725-0206

COMTAL
505 W Woodbury Rd
Altadena, CA 91001
(213) 797-1175

DeAnza Systems, Inc
118 Charcot Ave
San Jose, CA 95131
(408) 263-7155

EIKONIX Corp
103 Terrace Hall Ave
Burlington, MA 01803
(617) 273-0350

ESL, Inc
Sunnyvale, CA 94086
(408) 734-2244

Grinnell Systems Corp
2159 Bering Drive
San Jose, CA 95131
(408) 263-9920

Hamamatsu Corporation
Western Office
2680 Bayshore Frontage Road
Mountain View, CA 94043
(415) 965-2300

IKONAS Graphics Systems Inc
403 Glenwood Ave
Raleigh, NC 27603
(919) 833-5401

International Imaging Systems
650 N Mary Avenue
Sunnyvale, CA 94086
(408) 737-0200

Lexidata Corp
215 Middlesex Turnpike
Burlington, MA 01803
(617) 273-2700

NORPAK Ltd
Pakenham, Ontario, Canada
(613) 624-5555

QUANTEX Corporation
252 N Wolfe Road
Sunnyvale, CA 94086
(408) 733-6730

Ramtek Corporation
2211 Lawson Lane
Santa Clara, CA 95050
(408) 988-2211

Rank Precision Industries
Metrology Division
PO Box 36
Guthlaxton Street
Leicester LE2 OSP
England
0533-23801

MINICOMPUTER PROCESSOR CHARACTERISTICS

This section will define and review some of the key minicomputer system characteristics.

Word Length

Word length is defined as the number of bits (binary digits) that can be retrieved and stored from main memory during a single computer cycle. Most minicomputers commercially available on the market have a 16-bit word length. Other widely used models have word lengths of 8, 12, 18, 24, or 32 bits.

The word length of the minicomputer is probably its single most distinguishing characteristic. An 8- or 16-bit mini may be suitable for many functions related to data management and for control functions related to image processing, but a 24- or 32-bit mini may be more suitable for actual processing of image data or for purposes of "number crunching." The reason generally given for the desirability of the larger mini is that it has higher precision or directly addressable memory capability.

Software

Software is defined as the programming package and languages used to program the computer and to direct its operation. This area includes the operating systems, programming, and preprogrammed utility packages.

Assembler. An assembler is a special program that uses the computer's own power to facilitate the preparation of programs. The program-writing process is greatly simplified through a simplified format that uses mnemonic codes and symbolic addressing. The assembler program converts the symbolic instructions into an execution-oriented (machine) language ready to run on the computer.

A macroassembler is another software device to aid the programmer. A macroroutine can be called up and copied directly into a developing program, saving the rewriting time as well as the errors caused by reentry. The price of using this type of system is the high overhead memory requirement.

Compiler. A compiler is a software tool that facilitates the preparation of programs by shifting the task from the programmer to the computer. It simplifies the writing of programs into procedure-oriented languages and has the computer convert them into machine-oriented object programs. Compilers are found in virtually all mini and larger computer systems, mainly because of their proven ability to slash programming costs. They are frequently limited to a subset of the more standard programming languages, however. The following are some of the more common languages offered:

COBOL	(COmmon Business Oriented Language)
RPG	(Report Program Generator)
FORTRAN	(FORmula TRANslator)
BASIC	(Beginner All-purpose SymbolIC)
ALGOL	(ALGOrithmic Language)
PASCAL	

Operating System. The operating system is defined as that part of the computer system that facilitates the operation by handling such functions as

Scheduling, loading, and supervising the execution of programs
Allocating storage and I/O devices
Initiating and controlling I/O operations
Analyzing interrupt signals
Dealing with errors
Handling the human/computer communication interface
Controlling time-sharing operations

Typical modes of operating systems include the following:

Batch—The system processes the jobs sequentially and requires all data to be present before beginning.

Interactive—The system allows data to be entered during the job execution.

Real-time—The system responds to external demands on a priority basis.

Time-sharing—The system allows access to multiple users, sharing all its resources at the same time.

Language Implemented in Firmware. Language implemented in firmware defines whether the language processor is contained in microcode. The advantages are that it frees more memory space for the program and data, eliminates possible tampering, reduces system error, and enables the creation of more complex system functions at the hardware level.

Central Processor

Number of Directly Addressable Words. Short word length imposes a limitation upon the number of bits that can be assigned to hold the address part of each instruction. An example might be given for a typical 16-bit instruction with three parts: operation code, address mode field, and address. If 6 bits were assigned to hold the operation code and 2 bits to designate the addressing mode, only 8 bits or 256 direct memory locations would be left.

Common solutions to the limitations on directly addressable memory locations are the use of techniques like indirect addressing (the most prominent method used), multiword instructions, and indexing. In indirect addressing, the address part of the instruction specifies a storage location that contains another address rather than the operand itself.

Add Time. Add times are the times required to retrieve a one-word operand from main memory and add it to another operand already contained in an accumulator. Comparisons based on add times can be misleading because of differences in word lengths and instruction repertoires.

Hardware Multiply/Divide. Hardware multiply and divide capabilities can be either standard or optional. This capability eliminates the requirement for the multiplication and division processes to be performed by software means, thus significantly enhancing the speed of the system.

Hardware Floating Point. Hardware floating point is not a standard instruction for most of the currently available minicomputers. This option is essential to reduce the execution time in real-time image processing systems.

Real-Time Clock. A real-time clock enables the system to determine the time of day, a function essential to most data handling and storage systems.

Main Storage

Storage Type. Main storage for most minicomputers is generally one of two basic types: magnetic core or semiconductor.

Cycle Time. The cycle time is the minimum interval that must elapse between the start of two successive accesses to any one storage location. Cycle time is considered by many users to be one of the most significant characteristics of a computer's potential merit for use. However, the fastest cycle time does not necessarily mean that a particular computer will be the best machine for the overall job. Other factors, including the instruction set, the instruction and storage cycle efficiency, and its I/O capabilities, play an important role.

Access Time. The access time is the actual elapsed time between CPU request and the time that data are read. (See section 4, Storage Function).

Storage Capacity. It is important to have enough storage to hold all the programs, associated subroutines, and data as well as the capability to expand the main storage capacity if the need ever should arise.

Parity Check. Parity check can be either a standard or an optional feature. The reliability of modern core and semiconductor memories is so high that many manufacturers maintain that parity checking is a luxury unless absolute accuracy is an essential requirement.

Error Correction. Error correction involves the use of five of six bits from each memory word and special algorithms to allow the system to detect and correct single-bit errors.

Input/Output Control

Direct Memory Access (DMA). DMA permits the direct transfer of I/O data between main storage and peripherals. In minis without DMA, the I/O data transfer occurs via the processor's register under direct program control. DMA has two significant advantages over program-controlled I/O: it can accommodate higher I/O data rates, and it interferes least with normal processing operations.

Maximum I/O Rate. The maximum I/O rate is a measure of the computer potential to transfer data to and from peripheral or other external devices. In a machine with a DMA channel, the maximum I/O rate usually equals the cycle rate of the main storage unit.

External Interrupt Levels. The number of external interrupt levels indicates the number of different external devices that can interrupt the processor.

Communication

Maximum Number of Lines. The maximum number of lines indicates the number of communication lines that can be handled by a system.

Protocols Supported. Protocols supported indicate the type of communication protocols accommodated by the system.

MINICOMPUTER VENDORS

The following are some of the vendors that offer computers with word lengths of 16 bits or more:

Applied Data Processing Inc
33 Bernhard Road
North Haven, CT 06473
(203) 787-4107

Applied Systems Corporation
26401 Harper Avenue
St Clair Shores, MI 48081
(313) 779-8700

BTI Computer Systems, Inc
870 West Maude Avenue
Sunnyvale, CA 94086
(408) 733-1122

Burroughs Corporation
Burroughs Place
Detroit, MI 48232
(313) 972-7000

Cascade Data, Inc
6300 28th Street
SE Grand Rapids, MI 49506
(616) 942-1420

CDA (Computer Data Access), Inc
1373 Broad Street
Clinton, NJ 07011
(201) 473-4700

Century Computer Corporation
2339 Stanwell Circle
Concord, CA 94520
(415) 792-8000

Compal Computer Systems
6300 Variel Avenue, Suite E
Woodland Hills, CA 91367
(213) 992-4425

Computer Automation, Inc
18651 Van Karman Avenue
Irvine, CA 92713
(714) 833-8830

Computer Design Systems, Inc
8085 Wayzata Boulevard
Sacramento, CA 95834
(916) 929-2020

Computervision Corporation
201 Burlington Road, Route 62
Bedford, MA 01730
(617) 366-8911

Control Data Corporation
440 Computer Drive
Westboro, MA 01581
(617) 366-8911

Dataram Corporation
Princeton-Hightstown Road
Cranbury, NJ 08512
(609) 799-0071

Digital Equipment Corporation
129 Parker Street
Maynard, MA 01754
(617) 897-5111

Digital Scientific Corporation
11455 Sorrento Valley Road
San Diego, CA 92121
(714) 453-6050

Digital Systems Corporation
PO Box 158
Walkersville, MD 21793
(301) 845-4141

Dimis, Inc
1060 Highway 35
Middletown, NJ 07748
(201) 671-1011

Four-Phase Systems, Inc
10700 North DeAnza Boulevard
Cupertino, CA 95014
(408) 255-0900

Functional Automation, Inc
3 Graham Drive
Nashua, NH 03060
(603) 888-1905

General Robotics Corporation
55-57 North Main Street
Harford, WI 53027
(414) 673-6800

Olivetti Corporation of America
500 Park Avenue
New York, NY 10022
(212) 371-5500

Perkin Elmer Computer Systems Division
2 Crescent Place
Oceanport, NJ 07757
(201) 229-6800

Point 4 Computer Corporation
2659 McCabe Way
Irvine, CA 92714
(714) 556-4242

Prime Computer, Inc
40 Walnut Street
Wellesley Hills, MA 02181
(617) 237-6990

Raytheon Data Systems Company
1415 Boston-Providence Turnpike
Norwood, MA 02062
(617) 762-6700

Rolm Corporation
4900 Old Ironsides Drive
Santa Clara, CA 95050
(408) 988-2900

Sperry Univac Division, Sperry Rand Corporation
PO Box 500
Blue Bell, PA 19424
(215) 542-4011

Sperry Univac Minicomputer Operations
PO Box C-19504
2722 Michelson Drive
Irvine, CA 92713
(714) 833-2400

Harris Corporation Computer Systems Division
2101 West Cypress Creek Road
Fort Lauderdale, FL 33309
(305) 974-1700

Hewlett-Packard, Data Systems Division
11000 Wolfe Road
Cupertino, CA 95014
(408) 257-7000

Hewlett-Packard, GSD Division
19447 Prunridge Avenue
Cupertino, CA 95014
(408) 725-8111

Honeywell Information Systems, Inc
200 Smith Street
Waltham, MA 02154
(617) 890-8400

IBM Corporation, General Systems Division
PO Box 2150, NE
Atlanta, GA 30301
(404) 238-2000

Jacquard Systems
1639 11th Street
Santa Monica, CA 90404
(213) 450-6784

Melcom Business Systems, Inc
2200 West Artesia Boulevard, Suite 101
Compton, CA 90220
(213) 979-6055

Microdata Corporation
17481 Red Hill Avenue
Irvine, CA 92705
(714) 540-8341

Modular Computer Systems, Inc
1650 West McNab Road
Fort Lauderdale, FL 33310
(305) 974-1380

Mylee Digital Sciences, Inc
155 Weldon Parkway
Maryland Heights, MO 63043
(314) 567-3420

Nanodata Corporation
One Computer Park
Buffalo, NY 14203
(716) 631-6000

NCR Corporation
Main and K Streets
Dayton, OH 45479
(513) 449-2000

New England Digital Corporation
Main Street
Norwich, VT 05055
(802) 649-5183

Northern Telecom Systems Corporation
PO Box 1222
Minneapolis, MN 55440
(612) 932-8000

Northrop Data Systems
1160 Sandhill Avenue
Carson, CA 90746
(213) 637-1533

STC, Inc
Nine Brook Avenue
Marywood, NJ 07607
(201) 845-0500

Systems Engineering Laboratories, Inc
6901 West Sunrise Boulevard
Fort Lauderdale, FL 33313
(305) 587-2900

Tandem Computers, Inc
19333 Vallco Parkway
Cupertino, CA 95014
(408) 996-6000

Terak Corporation
14405 North Scottsdale Road
Scottsdale, AZ 85254
(602) 991-1580

Texas Instruments, Inc
PO Box 2909
Austin, TX 78769
(512) 250-7309

Wang Laboratories, Inc
836 North Street
Tewksbury, MA 08176
(617) 459-5000

4 STORAGE FUNCTION

The storage function is a major characteristic of data handling systems. For underwater search vehicles, the storage system sometimes is the most important factor in dictating the development of the optimum system. An optimum vehicle might be one that requires the storage of a major portion of the search data for later (post) processing. For that type of vehicle system, the critical development issue could be the availability of a suitable type of storage support system.

Main memory (storage) for a computer system is usually the most rapidly accessible memory, the one from which most, if not all, of the instructions in program are executed.

Auxiliary memory is distinguished from main memory by the fact that its contents (instructions and data) must be fetched into the main memory before processing in the computer arithmetic logic unit.

MAIN MEMORY CHARACTERISTICS: DEFINITION AND TERMINOLOGY

This section defines and reviews some of the key terms related to main memory. A brief description is given of the organizations, technologies, and system techniques associated with various memory designs.

From a hardware aspect, computer memory consists of a large number of individual "memory cells." A memory cell is a device or circuit that has two or more stable states. Usually, only two-state devices are used, each capable of storing a binary digit, or bit. The cells or bits are grouped into chunks such as bytes (8 bits) or words (8 or more bits).

Two important types of main memory are the read/write (R/W) memory and the random access memory (RAM). R/W memory permits data to be stored or retrieved at relatively comparable intervals of time in contrast to read-only memories (ROM) and read-mostly memories (RMM), which permit reading at about the same high speed as R/W memories, but are restricted from writing operations. ROMs are devices that may be written on only once and cannot be changed thereafter. RMMs are devices that may be erased and written on again, but by means of operations so much longer than the reading operation that the feasibility of utilizing the device as an R/W memory is inhibited.

In the random access memory (RAM), a second type of main memory, the time to access each stored word is constant and independent of the sequence in which the words were stored. A RAM contrasts with serial memories such as disks, drums, tapes, and shift registers, in which data are available only in the same sequence as originally stored or entered.

Memory timing is often referenced to access time and cycle time. Access time is the time required to read out from memory any randomly selected word. Cycle time is the minimum time interval required between the initiation (and execution) of two successive, independent memory operations. In some memory technologies, such as bipolar semiconductor, read and write cycle times are nearly equal. In magnetic cores the reading operation is destructive. Therefore, data must be rewritten on the core after each core reading, resulting in a total cycle time equal to both the read and rewrite operation. This characteristic leads to another method of classification that may be used to distinguish the various types of available memory technologies: destructive readout, as with magnetic cores, and nondestructive readout, as with semiconductors.

From a persistence aspect, the available types of memory may be described as static and dynamic. A static memory is one whose cells retain their states indefinitely as long as power is applied. Such memories do not require a clock for their operation, clocks usually being required only to synchronize memory operations with other parts or elements of the computer system. Examples of static memory devices are magnetic cores as well as semiconductor memories employing a bistable flip-flop for each memory cell.

The usual form of a dynamic memory cell is one that stores a binary digit as a charge on a capacitor. Since capacitors discharge with respect to time, this type of memory cell requires periodic refreshing, which is accomplished by reading and rewriting the cell content periodically under clock control.

A property considered important by many computer system designers is memory volatility. Nonvolatile memories retain their contents even after power is removed (eg ferrite core memories). Volatile memories lose their contents upon removal of power (eg semiconductor memories). Since main memory is not used for long-term storage of instructions or data, volatility is not a major concern. Nonvolatility is an important attribute of mass storage systems, however.

MAIN MEMORY TECHNOLOGIES: AN OVERVIEW

The oldest memory technology is the ferrite core. In spite of the newer technologies such as plated wire, thin film, and more recently semiconductors, magnetic-core memories continue to exist. Part of the reason is perhaps psychological, since system designers have become accustomed to thinking in terms of cores. Perhaps more important is the large investment made in core fabrication equipment, hence a reluctance to adapt to new technology.

Ferrite Core Memories

Cores have the advantages of zero standby power, reasonable cost for general-purpose applications (especially in large systems), and nonvolatility. Furthermore, core technology is mature and proven.

Ferrite cores have the disadvantages of large writing current, small readout signal requiring sophisticated read/write circuitry, high overhead (which makes magnetic memories for small systems uneconomic), and bulk.

Plated Wires

Plated wires do not offer distinct advantages over magnetic cores. Although simpler in wiring than cores, they have the disadvantage of low bit density. They are capable of much higher operating speeds and are non-destructive, reducing the complexity and cost of associated electronics. The readout signals are very weak. Thus, considerable cost is incurred in the electronics interfacing.

Semiconductors

Monolithic memory, integrated circuit memory, large-scale integrated (LSI) memory, very large-scale integrated (VLSI) memory, active memory, and transistor memory are semiconductor binary digital memories that employ an electronic circuit for each memory cell. Semiconductor memory has the advantage of high operating speed and, with the advent of LSI and VLSI technology in the last several years, very high density.

Because of the rapid changes in the present state of computer technology brought about by technological advances in the area of semiconductor VLS and

LSI in recent years, this document does not concern itself with assessing the state of the technology but merely presents key issues that designers of storage systems should be aware of.

In contrast to magnetic memories, semiconductor memories output dc levels that remain as long as the cell is accessed, thus simplifying the readout electronics. Since both input and output are compatible with the rest of the computer IC circuitry, interface problems are nonexistent.

There are two basic types of semiconductor memories: bipolar and MOS. In general, commercially available bipolar memories have high operating speed, obtained at the expense of high standby power and increased cost per gate. Therefore, their usefulness has been dictated mainly by the requirement for high speed.

MOS memories on the other hand dissipate less power and in general are easier to manufacture than bipolar memories, although the power and area savings are not very substantial.

AUXILIARY MEMORY

Auxiliary memory (AM) is distinguished from main memory in that its memory contents (instructions and data) must be transferred into the main memory before it can be executed or processed by the computer arithmetic logic unit. Auxiliary memories can be rewritten on many times without deterioration. Thus punch cards, paper tape, and other printer paper types are not classified as AM units. One of the main functions of AM is to store vast amounts of data for long periods. Nonvolatility is a very important requirement of a mass storage system.

The major interest in AM is from a search aspect, stemming from the possibility of the requirement for the system to store part or most of the data gathered during the search operation for future processing (post-processing). The stored data could comprise a duplicate (archive) of the data processed during the search, or unprocessed (raw) data that will be worked on at a later time and place.

Three types of AMs show possible promise for deep ocean underwater search applications:

Disk (fixed and moving head)
Magnetic tape
Magnetic bubble memory

DISK AUXILIARY MEMORY

Two major types of disk drives are widely used: fixed head and moving head. Fixed head (FH) disk drives can access blocks of data in 5 to 8 ms on the average. Their capacity ranges from 3×10^6 to 10×10^6 bytes. Each FH drive contains five to ten steel platters coated with iron oxide, aligned vertically on a common spindle. R/W heads extend between the platters, facing up and down from combs that suspended the heads and contain signal cables.

There is a head for each track; thus the delay in accessing a random block of data is due mainly to the rotational latency (ie 0 to 15 ms for a block of data to revolve to a position beneath the head). Although track lengths vary linearly with distance from the spindle, R/W heads are calibrated in such a way that the track capacities are all identical. Therefore, the transfer rate for data, whether read from inner or outer tracks, is universal. The average delay (time) for reading a random block of data is about half the maximum rotational latency.

Moving head (MH) drives are considerably cheaper to construct than FH drives, mainly because only two heads are required per platter. The cost per character for MH storage is typically 15% to 25% that of FH storage. MH drives generally permit removal of their disk-and-spindle socket assemblies, to provide the option of mounting single platters (disk cartridge) or multi-platters (disk pack) as required by various application programs.

The moving head single platter (MHSP) drive typically contains two thin combs with two R/W heads (fork). The fork is inserted and withdrawn radially according to the track address.

The moving head multiple platter (MHMP) drive is a multi-MHSP type with combs containing 2P - 2 heads, P being the number of platters. Typical drives have P = 6 or 11, corresponding to pack capacities of approximately 7×10^6 to 100×10^6 characters.

MHMP drives have the largest capacity of all hard-surface direct-access devices. Flexible substrate devices (tapes, photocopy, etc), have an inherently higher rate. The types of errors include both hard errors (unrecoverable errors), where a small recording area becomes permanently defective, and soft errors, where rereading or rewriting successfully avoids the anomoly. Hard-surface devices such as FH and MH drives normally operate for very, very long periods (months) without experiencing these types of errors.

High Density Disks

Disks and magnetic tapes use the same recording and playback principles. In recording, a thin layer of iron oxide containing magnetic dipoles is drawn past a recording head, which is an electromagnet with a highly focused fringing field. This process aligns the dipoles along the track in one or another direction to represent either digital 1s or 0s. For better reliability of the digital data, the medium is driven into magnetic saturation. This process is less vulnerable to noise mainly because the medium's response is exhausted. Furthermore, previously recorded data are more easily overwritten. By contrast, analog waveforms are generally recorded below saturation level.

In playback, the medium is drawn past another electromagnet or magnetoresistive transducer, and the magnetic flux generates a voltage in the read head. The system interprets flux changes as transition between the magnetic states (1s and 0s). Since the read head senses flux changes rather

than levels, the number of bits that can be written along a track is thus determined mainly by the number of flux reversals per unit length that can be read within the acceptable error rate. As the flux transitions get closer together, they begin to mutually interfere; as a result signal levels decrease. Since the signal output amplitude is also proportionally related to the track width, higher track densities lead to lower signal levels because of thickness, spacing, and gap-loss effects. The output goes through zero at a density such that the length of two oppositely magnetized regions is equal to the reading gap.

Errors may be caused by "dropouts" (missing bits) or "drop-ins" (extra bits). Dropouts usually occur when signal levels are lower than a specified threshold or when pulses are shifted in time and not synchronized with the reading clock. Signal levels fall below threshold most often when the head gap is increased by disk surface defects such as clumps of oxide or binding material, foreign matter, or voids in the disk coating. Drop-ins occur when interference between adjacent tracks or bits causes a shift in the peak signal or when voids or magnetic bumps on the disk cause discontinuities in the magnetization that are interpreted as extra 1s in a sequence of 0s. Shift in the peak signal can also be caused by noise from the medium, preamplifier, or read head. The practical error rate limit in particular media is about one in 10^8 recorded bits at high densities. This implies that some form of error detecting and correcting technique is needed in high density disk systems (ref 55).

High Density Rigid Disk

The state of the art in high density rigid disks is represented by a bit length of about 2 μm, a packing density of about $2000/mm^2$ (about 10 times that of semiconductor memory of highest density and roughly equal to a magnetic bubble memory of highest density), and a read/write rate of about 30 million bits per second. Disk storage costs per bit are about 1/100 those of semiconductor storage and about 1/10 those of bubble memory storage.

Disk access time is about 100 000 times longer than rival solid-state memories, but real-time processing of vast data files is possible through look-ahead data management.

High Density Floppy Disk

A floppy disk is usually made of a thin sheet of mylar coated with iron oxide. The disk rotates within a jacket, the R/W head contacting the disk through a narrow slot in the jacket. The standard floppy disk has a diameter of 8 inches; smaller minifloppies, diameters of 5-1/2 and 3-1/2 inches. Full floppies may contain up to 10 megabytes on 80 tracks. Double-sided minifloppies may contain up to 2 megabytes.

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55. Chi, CS, Higher Densities for Disk Memories, IEEE Spectrum, p 39-43, March 1981.

High performance rigid disks have diameters of 8 or 14 inches with capacities of 100 to 300 megabytes. The speed of typical hard disks is about 3000 rpm; floppies, 360 rpm.

Writing: Limiting Factor

The main limit to high density digital recording systems lies in the writing. The strength of the readout signal is dependent on the strength of the residual magnetization. Magnetized bodies tend to demagnetize partly, lowering the signal-to-noise ratio (SNR) and increasing the associated error rate.

The separation distance between the disk surface and the head is a major factor in reducing the signal strength. The signal strength decrease is an exponential function of the separation.

For the highest density, the flux-change pulses should be written as close together as possible without overlapping adjacent pulses. This can be accomplished by using narrow pulses of high amplitude. Pulse-width reduction may be accomplished by decreasing either the head-to-head separation, the head gap, or the thickness of the recording medium. A coating thickness of about 0.5 μm is the state of the art for rigid disks. In floppy disks, because of differences in the structure, the practical limit on coating thickness is about 1 μm.

Bit Density vs Track Density

There is a general tradeoff between bit density and track density. As track density increases, each track width becomes narrower. The resultant increase in adjacent track interference lowers the SNR. Also, as track density increases it becomes increasingly difficult to both position the head on the proper track and keep it there. The tracks may be displaced by such factors as deviation between the axis of the drive spindle and the true center of the disk, eccentricity of the disk, and vibration of the head actuators.

Two methods are available for correcting errors in track position through referencing information recorded near the information track: comparison of the amplitudes of the reference signals, and comparison of their arrival times.

The ultimate density depends on two components of distortion: a linear part, resulting in intersymbol interference, and a nonlinear part that depends on the recorded patterns of 1s and 0s and is inherent in the read/write process. The linear part can be corrected easily by linear equalization, since it can be characterized and is pattern dependent. Nonlinear distortion, on the other hand, is not predictable and is therefore the key factor in the limiting density.

Higher densities also depend on the characteristics of the recording heads. Conventional read/write heads are made of an electromagnet with a ferrite core (a piece of ceramic made of iron oxide particles mixed with nickel and zinc). When associated with high density disks, however, ferrite cores exhibit three major disadvantages: (1) their permeability exhibits poor

frequency response in recording above about 10 MHz, (2) the head dimensions are difficult to control accurately at track widths and magnetic gaps of less than 35 and 1 μm, respectively, and (3) the high inductance causes high-impedance noise and low head resonance.

Winchester Disk Drives

The "Winchester" designation was coined by IBM Corporation as a code name for a new technology of disk drives introduced in 1973. Although IBM no longer uses this term to describe any of its disk drives, the name is still used by others to categorize this new technology in disk drive originally developed by IBM.

Winchester disk drives are characterized by the following features (ref 56):

The disk, read/write heads, and actuator are contained in a hermetically sealed head assembly.

The read/write heads operate much closer to the disk surface than in systems with conventional disks.

The head load is much less than in traditional disk drives (10 grams as contrasted to 350 grams).

The head rests on the surface of the disk when the disk is not rotating.

The disk surface is lubricated to prevent head or disk damage.

The oxide coating on the disk surface is thinner.

The drives are fixed-disk types.

Winchester disk drives offer some significant advantages over traditional disk drives:

Greater reliability and maintainability as a result of the sealed head drive assembly, which virtually eliminates contaminate-caused failure. The requirements for air filters, cleaning, and head alignments are eliminated.

They could thus be ideal for shipboard application.

Greater bit packing and track densities as a result of lower operating head height (10 microinches or less).

Faster data transfer rates as the combined result of the faster rotating speed and greater packing densities.

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56. Datapro Research Corporation Report 70D6-010-50a, Memory and Storage: All About Winchester Disk Drives, Delran, NJ, January 1981.

More detailed discussion on Winchester disk technology and the Winchester market is provided by reference 56 on memory and storage.

MAGNETIC TAPE AUXILIARY MEMORY

Magnetic tapes are narrow (typically 0.5 inch wide) plastic film coated with iron oxide and typically about 2400 feet long. Information is stored on the tape transversely usually seven to nine bits per frame (character or byte) and longitudinally usually at one of the following densities: 200, 556, 800, 1600, or 6200 bytes per inch. Thus, a typical fully written reel of tape recorded at 1600 frames per inch may contain over 40 million bytes (ie 2400 ft x 12 in/ft x 1600 bytes/inch = 46 080 000 bytes).

Reading and writing are performed by a pair of heads (7 to 9 transducers) aligned transverse to the tape motion. During reading operations the read head senses the flux produced by the electromagnetic spots on the tape as it moves past the transducers. The write head is inactive during the reading operation. During the writing operation, the write head furnishes strong electromagnetic digital (binary) signals to the tape at precise time instances. The read head checks the newly written data a split second later by reading and comparing the bit pattern with the original bit pattern. If a mismatch occurs, a "write error" message is sent to the computer tape drive unit.

To detect recording errors and, in some advanced tape drives, to permit correction of those errors, two sets of check bits are written: parity bits and longitudinal check bits. In almost all types of drive, one or two parity bits are furnished to permit detection of all single-bit errors (ie substitution of 0 for 1 or vice versa).

Several frames of check bits are typically written at the end of each data block. Sophisticated R/W checking logic is contained in tape subsystems to determine whether frames have been transferred correctly to/from the tape.

High Density Digital Tape Recorders

High density digital recording is a relatively new method of recording information on magnetic tapes. This type of system offers several significant advantages over conventional analog recording methods. First the data are recorded in a format that is directly compatible with electronic data processing equipment. Second, the data are reproduced with a much higher degree of accuracy because of the relative insensitivity of digital data to the effects of flutter and time base error, which tend to degrade analog signals.

According to a publication by Bell and Howell (ref 57) on a high density digital recording system, a packing density of up to 33 000 bits per inch per track is possible. High density packing makes possible a transfer rate of

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57. Bell and Howell Document, Parallel Mode High Density Recording Technical Fundamentals, Bell and Howell Company, Datatape Division, Pasadena, CA, 1979.

about 600 million bits per second, with errors of less than one per million bits.

As usually considered, high density digital recording systems are those that have a recording per-track density of 20 000 bits per inch or greater, using longitudinal techniques. The system is termed as "serial" high density if the individual bit streams are recorded one bit stream per track. If the bit stream consists of parallel bytes of N bits recorded across N tracks on the tape, the system is termed a "parallel" high density digital system.

Tape Recorder: Problems and Alternatives

The magnetic tape recorder offers the highest storage density of all available types of archived storage media. It exhibits many features (size, weight, cost, storage density, etc) that make it very attractive for incorporation into the various data handling concepts for underwater search systems. The tape recorder has been used for many years as a data gathering and archival unit for aircraft flight recorders, satellites, submarines, etc, but it has not been without problems. In a study sponsored by the National Aeronautics and Space Administration (NASA) Langley Research Center (LRC), it was determined that tape recorders are the most failure-prone components on US spacecraft (ref 58).

In an effort to research improved new storage technology as an alternative to the tape recorder, LRC sponsored the Applied Physics Laboratory (APL) at Johns Hopkins University to study the problem and investigate the use of magnetic bubble memory as a possible alternative. A report that summarizes this study (ref 58) cites the chief drawback to present-day tape recorders as their susceptibility to early failure. Among recorders launched on NASA spacecraft in the 60s and early 70s, representing 36 different designs from 10 manufacturers (not cited), 35 out of 163 failed in orbit. The overall failure rate was 114 per million operating hours, which is 13 times worse than the failure rate exhibited by other entire satellites not using recorders. Furthermore, it was noted that failure rates of the other systems declined as the year progressed, while the failure rate of the tape recorder showed no improvement.

The poor reliability of tape recorders, as implied by reference 58, can be attributed mainly to the complexity of their mechanical components. The stresses of orbital launch and the lack of periodic maintenance create a situation which often brings on mechanical failure.

Another tape recorder characteristic that has relevance to the search system problem is that the rotating parts, if not carefully designed, could transfer net angular momentum to a small vehicle. And some recorders use hysteresis synchronous motors with square-wave drive, which produces radio-frequency and electromagnetic interference that could interfere with other circuitry if not properly shielded.

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58. Hoffman, EJ, RC Moore, and TL McGovern, Designing a Magnetic Bubble Data Recorder, Computer Design, vol 15, no 3, p 77-85, March 1976.

A high density magnetic bubble data recorder could be an alternative replacement for the magnetic tape recorder. The advantage to be gained would be the elimination of all mechanical moving parts.

Tape Recorders: On-Board Underwater Vehicles

UARS. The Unmanned Arctic Research Submersible (UARS) is a system developed by the Applied Physics Laboratory (APL), University of Washington, to allow exploration of the near-surface and under-ice region of the Arctic (ref 59).

The UARS is a compact vehicle with a weight of 900 lb in air, a length of about 10 ft, and a diameter of 19 in. The vehicle has a torpedo-shaped body designed for carrying instruments for basic or applied research; its associated subsystems support vehicle launching, tracking, command, and recovery. There are several ports in the body where oceanographic, optical, and acoustic instruments can be mounted. The system also contains an internal digital recording system with capacity for high-resolution recording (1000 binary bits per second for 10 hours) during operation.

The data recording system is described (ref 59) as a system designed to operate with a low-speed magnetic tape recorder to obtain high-resolution, high-density data at a relatively low data rate. To achieve this, the signals are converted to binary form and recorded on magnetic tape by the non-return-to-zero change-at-one (NRZ1) recording method. A nine-track recording head is used on 1/2-inch magnetic tape, and the data are recorded across the tape in a parallel-serial combination in which time multiplexing is used to separate the channels.

Reference 59 indicates that several of these magnetic tape transport units have been built and used in field operations with excellent results. They are limited-purpose units, designed for recording only, with no playback capability. They are very compact and have low power drain.

UFSS. The Unmanned Free-Swimming Submersible (UFSS) vehicle was designed and built by Naval Research Laboratory to demonstrate and evaluate advanced technologies as applied to underwater vehicles (ref 60). One of the components of the telemetry subsystem was a data acquisition system that served the purpose of both gathering and storing data for postanalysis. A high-speed cassette tape recorder was used for on-board storage. Some of the types of data recorded were as follows:

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59. Washington University Applied Physics Laboratory TR APL-UW 7219, Unmanned Arctic Research Submersible (UARS) System Development and Test Report, by RE Francois and WE Nodland, 11 September 1972.

60. Naval Research Laboratory Report 8459, The NRL Unmanned Free-Swimming Submersible (UFSS), by PB Alers and HA Johnson, 31 December 1981.

Time
Propulsion current
Upper/lower rudder position/command
Port/stbd elevator position
Pitch rate/angle integrator
Roll rate/angle
Yaw rate
Heading
Propeller rpm
Power supply voltages/currents/temperature
Sync word
Data type
Record number
Trim and ballast status
Motor controller temperature
CPU temperature
Ambient air temperature
Pressure vessel temperature
Water temperature/conductivity/velocity
Depth
Failsafe status
Omega fix

BUBBLE AUXILIARY MEMORY

Magnetic bubble memories have several major advantages over other mass storage devices:

They are solid-state devices, thus have no moving parts that could wear out or become contaminated.

They are nonvolatile, unlike other solid-state silicon-based devices (ROMs, RAMs).

They are simple devices to produce, requiring only a single mask step and a high production imperfection tolerance.

They are much faster than floppy disks, with access time similar to those of hard disks and transfer rates approaching 1 megabit per second (ref 61).

Bubble Memory Systems vs Floppy-Disks

Both bubble and floppy-disk systems offer low-cost moderate capacity mass storage. Bubbles have the advantage of being faster and quieter and having lower power consumption and smaller physical size. Floppies, on the other hand, provide an inexpensive, removable storage medium.

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61. Foreman, AC, Bubble Memory, Digital Design, p 26-37, June 1981.

Survey of Available Bubble Memory Systems

Complete bubble memory systems are available that can be plugged directly into DEC LSI-11s, Intel MULTIBUS systems, S-100 systems, TI 9900s, the STD bus machine, and others. The average small-quantity price for these systems is currently in the area of $25/kbyte (ref 61).

The TI 92-kbit bubble device has the distinction of being the first in successful production. It is by and large the most popular design, offering the lowest per-bit cost. The following are some of the available bubble memory devices:

Manufacturer	Type	Capacity (kbits)	Access Time (ms)
Texas Instruments	TIB0203	92	4.0
Texas Instruments	TIB0500	512	11.2
Texas Instruments	TIB1000	1000	11.2
National	NBM-2256	256	7.0
National	NBM-2011	1000	11.2
Intel	7110	1000	40.0
Fujitsu	FBM 31DB	64	370.0
Fujitsu	FBM 32DA	64	4.5
Fujitsu	FBM 43DA	256	6.0

Characteristics and Definitions

Because of the similarity in disk and bubble operational characteristics, the seek-time, access-time, transfer-rate and error-rate performance of a disk can be applied to bubble memory as well.

Seek Time. In a disk system, the seek time is normally defined as the time taken by the RW head to move into the track where the relevant data are located. In bubble systems, the seek time depends upon the number of bit positions or "pages" in the minor loops and the bubble shift rate. Most current bubble devices are designed to be shifted at a 100 kHz rate with the minor loops containing from 64 to 4096 bit positions, or pages. Thus, the worst-case seek time is the number of pages multiplied by 10 μs or between 0.64 and 41 ms. The average will be half the worst case.

The average seek time for a typical floppy disk is about 400 ms and for a typical hard disk over 50 ms. Thus, the seek time for bubble systems is better than two orders of magnitude faster than floppies, and five to eight times faster than hard disks (ref 61).

Access Time. The access time for disk devices includes the seek time, any required head settling time, and the rotational latency of the disk drive. For bubble systems the access time includes the seek time and the time required to shift the read track or minor loop so that the first bit of data is under the read detector. Typically it takes about 100 shifts, or 1 ms, to move the read data to the detector. Thus bubble access time can be calculated by adding 1 ms to the calculated seek time (ref 61).

The rotational latency alone for a typical hard disk averages over 7 ms; for a floppy, 50 ms. The result is that bubble systems provide access times that are 25 to 100 times faster than most disk systems.

Transfer Rate. The effective data transfer rate between the bubble device and the computer depends mainly on the bubble shift rate and the number of active bubble devices at any given time. For serial operation the effective transfer rate could be slower than the bubble shift rate. When operated in parallel however, the transfer rate increases by equal proportionality. Bubble-Tec's HDC/HDB-11 system for LSI-11s, with four devices operating in parallel, has a peak transfer rate of about 800 kbits/s, about three times better than the typical 250 kbit/s transfer rate of a floppy but 1/3 the 2.5 Mbit/s transfer rate of a hard disk (ref 61).

Error Rate. Tests of bubble devices by their manufacturers have shown typical soft error rates of 10^{-9} and hard error rates of 10^{-12}. These rates are comparable to those obtained from floppy systems using high-quality diskettes.

System Design Considerations

The design of systems using bubble memory is much more complex than the design of systems using other forms of solid-state memories. Most semiconductor memory devices require relatively few not particularly critical control signals. Bubble devices, on the other hand, require many precisely controlled signals. Thus, bubble systems can involve a great deal of support logic.

5 SYSTEM-LEVEL DISCUSSION

The process of detecting, classifying, and recognizing a target for current sonar search systems can be analyzed from the standpoint of statistical decision theory. The observer can be thought of as estimating the prior and posterior probabilities that the target was actually present, then using some criterion (ie thresholding a likelihood ratio) to make his decision. The choice of this criterion determines the probabilities of missing an actual target and of reporting false targets. The tradeoff between these probabilities, as a function of the criterion used, is commonly referred to in the sonar and radar community as the observer's "receiver operating characteristic" (ROC).

The perceptual decision criteria of the search operator are influenced by many factors aside from the physical nature of the target. Experience plays an important role, affecting the estimation or prior probabilities in

particular. At present, most of the existing search systems rely on the expertise of the search operator or coordinator to make decisions governing the search. The decisions, based on the interpretation of the output of the sensors, inevitably affects the progress and end results of the search.

The many different sensor display systems found on current underwater unmanned search systems are separate independent entities specifically geared for the presentation of only one particular type of sensor output (eg sonar graphic recorder, navigation graphic display, television video CRT). There are no capabilities to merge and integrate the sensor data sources (navigation, compass, altimeter, SLS, FLS, etc) into a single collective display unit. Therefore, the task to consolidate all these separate data sources lies with the operator. A data handling and display system designed to collectively integrate, merge, and enhance relevant graphic and video data could greatly improve the operator's ability to conduct a search operation.

DATA HANDLING AND DISPLAY SYSTEM CONSIDERATIONS

The existing research literature is certainly a crucial source of information for the data handling and display designer, but a number of shortcomings prevent its use as the definitive guide in solving design problems. Among its shortcomings are the absence of data that would validate the outcome of laboratory studies as predictors of deep ocean work site performance and the absence of detailed information and of a decision system for considering the consequences of cost, complexity, and reliability factors. Consequently, the conclusions and recommendations of this study, while guided by its research findings, must be supplemented by deductions from the design models and weighted by speculations concerning the practical consequences of cost-complexity-reliability factors.

Today, we are far from ready to design a totally autonomous search system. Yet it seems clear that, within the limits of existing technology, that should be one of the designer's goals. The variety of tasks and conditions encountered in deep ocean search missions requires general-purpose systems. In order to take advantage of the human operator's great potential in such systems we must provide as much perceptual information as possible along with a display and modes of data handling that are compatible with the operator's sensory systems. To accommodate problems of fatigue and limits of attention, computer-controlled automated procedures should be added to the system.

To specify the functions of a data handling system for a search-related display and processing system, it is necessary to examine the operational scenario. Such an analysis of current underwater search systems reveals the following set of top-level functional requirements:

Display of sensor imagery and graphical data.

Review or search for area of interest, often over a very large area.

Merging and correlating of multiple-sensor image sources and graphics information.

Interactive processing to enable information extraction and enhancement.

Output of processed data and information.

The display acts as a technologically and economically limited interface between the operator and the search (data handling) system. Within those limitations, the top-level requirements can be translated into the following set of data handling and display functional capabilities to support the search process:

Real-time image processing
  Image correction, enhancement, and restoration
  Geometric correction
  Multisensor data integration

Data Management and storage
  Layered and relational data structure

Display system control function
  Video control
  Display presentation control
  Processing control
  Interactive control

Each of these three functional capabilities is discussed in the following paragraphs.

Real-time Image Processing

Speed is a figure of merit for an operational system. The faster the system, the higher its operational desirability. Granted that there are other driving factors, from an idealistic operational stance we are safe in making this hypothesis. It implies that the ideal data handling system for any undersea search vehicle system must work in a real-time or near-real-time mode, providing instantaneous processing of incoming data. Instantaneous processing is not actually possible, since there will always be some time delay, whether it be the time it takes for a TV frame to update with a new image or for an electronic impulse to traverse a conductor.

The AUSS model has demonstrated that the most effective type of vehicle is a free-swimmer. Although from the operational perspective it is easy to criticize the model on many of its assumptions, a free-swimmer has many desirable advantages over a towed vehicle, the largest being its capabilities to investigate promising contacts immediately and to be more easily employed and supported. A very small search system is ideal in that it can be deployed by either ships or aircraft.

The major problems in implementing such a system are the requirements for a large bandwidth and high-volume data handling capabilities. The historical summary of search operations conducted by NOSC in FY80 indicated that most targets were small and that video was used to locate at least half

of the targets. The use of video in the detection scheme imposes a bandwidth requirement on the telemetry link that far exceeds, by orders of magnitude, the capability of an acoustic link. Several alternatives could be employed to overcome this problem:

Give up the concept of a free-swimmer.

Accept an extremely slow search rate and provisions to scan, stop, and transmit data to the surface.

Make the free-swimmer "intelligent"—transmit only important data to the surface.

All present search systems are to a very high degree, if not totally, dependent on the surface vessel to perform the necessary data handling functions, ie

Target detection, classification, and identification (signal processing in general)

Data storage and archiving

Vehicle command and control

Thus there is a large gap in our body of knowledge relating to the development of real-time data handling systems for underwater search vehicle application. Very little information is available to support the feasibility of applying or transferring the data handling functions to the vehicle.

However, the technology—which once limited the amount of real-time information processing that a search system could perform on its own—has seen explosive advances in the past 10 years. There are several new opportunities that can be applied to a search system construction, in such areas as microprocessors, solid-state and magnetic memory, A/D converters and solid-state controllers, LSI special-purpose processors (eg, floating point processors, array processors, and image processing hardware), and computer communications.

The 16-bit microprocessors (eg, Z8000 and MC68000) have high potential for search vehicle system development. There are current efforts to apply this class of processors to such tasks as image processing for robot control. As yet, however, very little experience has been gained with these systems for underwater vehicle applications of this type. And with the advent of the recently developed 32-bit microprocessor system, which promises mainframe computing power in very compact packages, it will be possible to construct tremendously complex onboard automatic information processing systems capable of real-time performance.

Real-time image processing appears to have major technological and economic limitations that force restrictions on system flexibility and utility. The display can provide real-time processing for only a limited amount of imagery, which research evidence suggests will generally involve data correction, enhancement, restoration, correlation, and integration. The specific processing employed will be determined by the available assets and the particular search requirement.

Data Management and Storage

The display must be interfaced to the external system. A computer interface allowing the data to be loaded and unloaded between the refresh memories and external mass storage devices is required, together with control information from the system host computer.

A data base management system is a software system intended to manage and maintain data in a prescribed structure for the purpose of its processing by multiple applications independent of storage device class or access method. A data base management system organizes data elements in some predefined structure and retains relationships between various data elements within the data base.

A data management system, on the other hand, is one that is intended primarily to permit access to and retrieval from already existing files, usually for a single application.

Although a data management system may provide the capabilities of minimizing data redundancy, modifying elements within a file, and centralizing the storage of data, its principal intent is to perform such functions as information retrieval, report generation, and inquiry for single application.

New hardware systems and data base management techniques such as relational data structure and distributed data bases have the potential to balance the demands of real-time sensor data processing and control with the need to retrieve, correlate, and store a large quantity of data. Memory management techniques such as the virtual memory technique, which combines main memory with mass memory (auxiliary memory), offer the programmer with an effectively unlimited amount of main memory available for programming. Current systems are limited by inability of the interface to handle the required data rates.

Display System Control Function

The display system is the source of information for the operator about the spatial features of the search site and objects detected on the ocean bottom. There appear to be (1) a ready market supply of suitable acoustic, optical, magnetic, electric, and electromagnetic sensor systems that meet the deep ocean requirements (see ref 62, 63 for a recent survey and recommendations) and (2) adequate recommendations regarding the technical aspects of display features including viewing distance, contrast ratio, ambient lighting, color, and gray scale (ref 5, 6, 16, 38, 45, 48, 64). There also appear to

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62. Naval Research Laboratory Report CG-D-38-80, Forecasting of Remote Underwater Sensing Technology, by VA Del Grosso and PB Alers, July 1980.

63. SEACO Inc Final Report 80-09-04, Cameras for an Underwater Viewing System, by K Perreira, SEACO Inc, Kailua HI, September 1980.

64. NOSC TR 235, Evaluation of Diver Television Systems, by RB Fugitt and RW Myers, May 1978.

be (1) a ready market supply of suitable image processing hardware (see ref 54, 56, 65 and appendix A) and (2) adequate recommendations regarding the technical aspects of image processing and analysis (ref 41-43, 52, 66, 67).

Theory and research indicate that the display system must be human engineered to possess a suitable operator-machine interface and to include interactive controls such as the following:

Video control
- Image channels for display and processing
- Graphic channels for display and processing
- Alphanumeric and test pattern display

Display presentation control
- Scroll or pan
- Zoom ratio
- Split screen
- Psuedocolor (look-up table control)
- Image and graphic data merge (maps and charts)

Processing control
- Application software
- Spatial/temporal processor control
- Image combination
- Alphanumeric and special character generator
- Vector to raster converter

Interactive control
- Emulate conventional terminal
- Receive interactive inputs (keyboard, trackball, joystick, mouse, tablet)
- Position cursor

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65. The Directory of Computer Graphics Suppliers, Harvard Newsletter on Computer Graphics, Harvard University Laboratory for Computer Graphics, Sudbury MA, April 1981.

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SYSTEM DESIGN GUIDELINES

Research and experience from the development of related types of data handling, display, and image processing systems indicate that the system design must allow for changes in requirements over the lifetime of the system. In order to do this, the system must possess three attributes: flexibility, programmability, and modularity.

Flexibility allows the system (display, processing, and storage) to be used for a diverse range of applications (various data formats, processing algorithms, etc). The technical approach is to generalize hardware and implement the specific operations in software or firmware.

Programmability means that all the data handling functions can be software controlled. This implies that the hardware portion is software configurable and able to handle various tasks requiring different data formats and processing techniques. "Hard wiring" the design to perform specific functions has been outmoded by current technology and the rapidly evolving state of the art.

Modularity is a key to system diversification in both size and level of processing sophistication. A modular system has the advantage of being highly flexible. At the time of acquisition, the system can be configured to satisfy the immediate requirements. Other capabilities may be added as appropriate throughout the life of the system.

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APPENDIX A: IMAGE PROCESSING HARDWARE MARKET DATA

	Manufacturer and Model	
	Applied Data Processing Resource/100	Applied Systems Corporation ASC/80
Word length, bits	16	16
Software		
Compiler	BASIC	BASIC, FORTRAN, PASCAL, PI/M
Operating system	Time-sharing	Time-sharing
Language implemented in firmware	No	Optional
Price ($)		
CPU	Contact vendor	1900 (basic system)
Central processor		
No. of directly addressable words	256k	64k
Add time, microseconds	0.80	1.0
Hardware multiply/divide	Optional	Optional
Real-time clock or timer	Optional	Standard
Main storage		
Storage type	Core	MOS
Cycle/access time	0.8/0.4	1.0/0.5
Min/max capacity, words	65k/256k	4k/128k
I/O control		
DMA	Standard	Optional
Maximum I/O rate, word/s	1.1M	50k
No. of external interrupt levels	16	8 optional
Communications		
Asynchronous	Std, 1200 baud	Opt, to 50k bps
RJE terminals emulated	2780	-
Peripheral equipment		
Floppy disk (diskette) drives	No	0.24M-2M bytes
Disk pack/cartridge drives	Both, 10M, 320M bytes	Optional
Drum/fixed head disk storage	No	Optional, 10-100M
Serial printer	Yes, 120-180 cps	30/180 cps
Line printer	Yes, 300-600 lpm	A/R optional
Data communication interface	Yes, 19.2k bps	To 19.2k bps

Manufacturer and Model	BTI 5000	BTI 8000
Word length, bits	16	16
Software		
Compiler	BASIC	BASIC, FORTRAN, COBOL, PASCAL
Operating system	Time-sharing	Time-sharing, batch
Language implemented in firmware	Partially	No
Price ($)		
CPU	29950	86750
Central processor		
No. of directly addressable words	NA	–
Add time, microseconds	20	3.5
Hardware multiply/divide	Standard	Standard
Real-time clock or timer	Standard	Standard
Main storage		
Storage type	MOS and core	Core
Cycle/access time	0.60	0.67
Min/max capacity, words	64k/64k bytes	256k/8M bytes
I/O control		
DMA	Standard	4 to 32
Maximum I/O rate, word/s	616k	10M
No. of external interrupt levels	NA	–
Communications		
Asynchronous	Std, to 9600 bps	Std, to 19200 bps
RJE terminals emulated	No	No
Peripheral equipment		
Floppy disk (diskette) drives	No	No
Disk pack/cartridge drives	Nonremov pack, 29M-392M bytes	Pack, 33M-8G bytes
Drum/fixed head disk storage	No	No
Serial printer	No	No
Line printer	300, 600, 900 lpm	300, 600, 900 lpm
Data communication interface	9600 bps, async	19.2 bps, async

	Manufacturer and Model	
	Burroughs B720/B730	Burroughs B770 Series
Word length, bits	64	16
Software		
Compiler	COBOL, RPG, AEL	COBOL, RPG, NDL, MPL
Operating system	Real-time	Batch, real-time
Language implemented in firmware	Fully	Fully
Price ($)		
CPU	Contact vendor	Contact vendor
Central processor		
No. of directly addressable words	-	-
Add time, microseconds	0.43	-
Hardware multiply/divide	No	-
Real-time clock or timer	No	Standard
Main storage		
Storage type	MOS	Core, MOS
Cycle/access time	1.0/0.5	1/0.4, 0.63
Min/max capacity, words	32k/96k bytes	32k/64k
I/O control		
DMA	Standard	Standard
Maximum I/O rate, word/s	2M bytes	2M bytes
No. of external interrupt levels	-	-
Communications		
Asynchronous	To 9600 bps	To 9600 bps
RJE terminals emulated	IBM 3780	IBM 3780
Peripheral equipment		
Floppy disk (diskette) drives	243k-1.5M bytes	243k bytes
Disk pack/cartridge drives	Cartridge, 4.6-27.6M bytes	Cartridge, 4.6-27.6M bytes
Drum/fixed head disk storage	No	No
Serial printer	60 cps	No
Line printer	85-400 lpm	85-750 lpm
Data communication interface	9600 bps	9600 bps

	Manufacturer and Model	
	Burroughs B800 Series	Burroughs B1720 Series
Word length, bits	64, 16	64
Software		
Compiler	COBOL, RPG, NDL, MPL	COBOL, RPG, FORTRAN, BASIC, UPL, NDL
Operating system	Batch, real-time	Batch, real-time
Language implemented in firmware	Fully	Fully
Price ($)		
CPU	35045 (32k bytes)	Contact vendor
Central processor		
No. of directly addressable words	-	-
Add time, microseconds	-	-
Hardware multiply/divide	-	-
Real-time clock or timer	Standard	No
Main storage		
Storage type	MOS, bipolar	MOS, bipolar
Cycle/access time	1.0/0.5	1.0/0.67
Min/max capacity, words	32k/150k bytes	4.8k/256k bytes
I/O control		
DMA	Standard	Optional
Maximum I/O rate, word/s	2M bytes	-
No. of external interrupt levels	-	-
Communications		
Asynchronous	To 9600 bps	To 9600 bps
RJE terminals emulated	IBM 3780	HASP, IBM/360
Peripheral equipment		
Floppy disk (diskette) drives	2M bytes	No
Disk pack/cartridge drives	Both, 4.6-130.4M bytes	Both, 2.3-697.6M bytes
Drum/fixed head disk storage	Fixed head, 9.4-65.6M bytes	Fixed head, 1.9-70M bytes
Serial printer	120 cps	No
Line printer	160-750 lpm	85-1040 lpm
Data communication interface	9600 bps	9600 bps

	Manufacturer and Model	
	Burroughs L9000 Series	Cascade Data Concept II
Word length, bits	64	16
<u>Software</u>		
Compiler	COBOL	RPG
Operating system	-	Batch, real-time, time-sharing
Language implemented in firmware	Fully	No
<u>Price ($)</u>		
CPU	17490	22200 (32k bytes)
<u>Central processor</u>		
No. of directly addressable words	-	32k
Add time, microseconds	-	8.8
Hardware multiply/divide	-	Standard
Real-time clock or timer	-	Optional
<u>Main storage</u>		
Storage type	MOS	Core
Cycle/access time	1.5/1.2	1.0/0.35
Min/max capacity, words	4k/48k bytes	16k/64k
<u>I/O control</u>		
DMA	-	Standard
Maximum I/O rate, word/s	-	413k
No. of external interrupt levels	-	0
<u>Communications</u>		
Asynchronous	-	Standard
RJE terminals emulated	-	None
<u>Peripheral equipment</u>		
Floppy disk (diskette) drives	No	No
Disk pack/cartridge drives	No	Cartridge, 400k bytes
Drum/fixed head disk storage	No	No
Serial printer	60, 90, 120, 150 cps	55 cps
Line printer	90-250 lpm	125-600 lpm
Data communication interface	9600 bps	9600 bps

	Manufacturer and Model	
	Cascade Data Concept III	CDA Inc DG IT Series
Word length, bits	16	16
<u>Software</u>		
Compiler	RPG	ALGOL, BASIC, FORTRAN
Operating system	Batch, real-time time-sharing	Real-time
Language implemented in firmware	No	No
<u>Price ($)</u>		
CPU	26900 (16k bytes)	Contact vendor
<u>Central processor</u>		
No. of directly addressable words	64	1024
Add time, microseconds	7.5 (word)	0.84
Hardware multiply/divide	No	Optional
Real-time clock or timer	Standard	Standard
<u>Main storage</u>		
Storage type	MOS	MOS
Cycle/access time	0.5/0.5	0.96/0.50
Min/max capacity, words	32k/64k	32k/32k
<u>I/O control</u>		
DMA	Standard	Standard
Maximum I/O rate, word/s	413k	2M bytes
No. of external interrupt levels	0	16
<u>Communications</u>		
Asynchronous	Standard	Optional (4)
RJE terminals emulated	None	2780/3780
<u>Peripheral equipment</u>		
Floppy disk (diskette) drives	1.2M bytes	630k bytes
Disk pack/cartridge drives	Cartridge, 40M bytes	Cartridge, 10-20M bytes
Drum/fixed head disk storage	No	No
Serial printer	55 cps	(1) 80, 160 cps
Line printer	125-600 lpm	No
Data communication interface	9600 bps	Yes

	Manufacturer and Model	
	CDA Inc DG MP/100 Series	CDA Inc DG NOVA Series
Word length, bits	16	16
Software		
Compiler	ALGOL, BASIC, FORTRAN	ALGOL, BASIC, FORTRAN
Operating system	Real-time	Real-time
Language implemented in firmware	No	No
Price ($)		
CPU	Contact vendor	Contact vendor
Central processor		
No. of directly addressable words	1024	1024
Add time, microseconds	0.84	0.40
Hardware multiply/divide	Optional	Optional
Real-time clock or timer	Standard	Standard
Main storage		
Storage type	MOS	MOS
Cycle/access time	0.96/0.50	0.40/0.50
Min/max capacity, words	32k/32k	64k/128k
I/O control		
DMA	Standard	Standard
Maximum I/O rate, word/s	2M bytes	2M bytes
No. of external interrupt levels	16	16
Communications		
Asynchronous	Optional (16)	Optional (16)
RJE terminals emulated	2780/3780	2780/3780
Peripheral equipment		
Floppy disk (diskette) drives	630k bytes	630k bytes
Disk pack/cartridge drives	Cartridge, 10-20M bytes	Cartridge, 10-20M bytes; pack, 96M bytes
Drum/fixed head disk storage	No	No
Serial printer	(2) 80, 160 cps	(8) 80, 160 cps
Line printer	No	No
Data communication interface	Yes	Yes

Manufacturer and Model	Century Computer 300	Century Computer 400
Word length, bits	8, 16	8, 16
Software		
Compiler	BASIC	BASIC
Operating system	Real-time	Real-time
Language implemented in firmware	No	No
Price ($)		
CPU	16500	26500
Central processor		
No. of directly addressable words	64k bytes	64k bytes
Add time, microseconds	1.4 (16 bits)	1.4 (16 bits)
Hardware multiply/divide	Standard	Standard
Real-time clock or timer	Standard	Standard
Main storage		
Storage type	MOS	MOS
Cycle/access time	0.4/0.2	0.4/0.2
Min/max capacity, words	32k/64k bytes	32k/64k bytes
I/O control		
DMA	Standard	Standard
Maximum I/O rate, word/s	1.6M bytes	1.6M bytes
No. of external interrupt levels	15	15
Communications		
Asynchronous	Std, 19200 bps	Std, 19200 bps
RJE terminals emulated	–	–
Peripheral equipment		
Floppy disk (diskette) drives	No	No
Disk pack/cartridge drives	Both, (10) 320k bytes	Both, (10) 320k bytes
Drum/fixed head disk storage	No	No
Serial printer	165 cps	165 cps
Line printer	150 lpm	150 lpm
Data communication interface	9600 bps	9600 bps

	Manufacturer and Model	
	Century Computer 700	Century Computer 900
Word length, bits	8, 16	8, 16
<u>Software</u>		
Compiler	BASIC	BASIC
Operating system	Real-time	Real-time
Language implemented in firmware	No	No
<u>Price ($)</u>		
CPU	34000	42500
<u>Central processor</u>		
No. of directly addressable words	64k bytes	64k bytes
Add time, microseconds	1.4 (16 bits)	1.4 (16 bits)
Hardware multiplv/divide	Standard	Standard
Real-time clock or timer	Standard	Standard
<u>Main storage</u>		
Storage type	MOS	MOS
Cycle/access time	0.4/0.2	0.4/0.2
Min/max capacity, words	96k/256k bytes	160k/112k bytes
<u>I/O control</u>		
DMA	Standard	Standard
Maximum I/O rate, word/s	1.6M bytes	1.6M bytes
No. of external interrupt levels	15	15
<u>Communications</u>		
Asynchronous	Std, 19200 bps	Std, 19200 bps
RJE terminals emulated	–	–
<u>Peripheral equipment</u>		
Floppy disk (diskette) drives	No	No
Disk pack/cartridge drives	Both, (10) 640k bytes	Both, (10) 1200k bytes
Drum/fixed head disk storage	No	No
Serial printer	165 cps	165 cps
Line printer	150 lpm	150 lpm
Data communication interface	9600 bps	9600 bps

	Manufacturer and Model	
	Compal 9000	Computer Automation *Naked Milli* LSI-3/05
Word length, bits	16	16
<u>Software</u>		
Compiler	BASIC, FORTRAN, PASCAL	FORTRAN
Operating system	Real-time	Real-time
Language implemented in firmware	No	No
<u>Price ($)</u>		
CPU	19995	825 (Alpha)
<u>Central processor</u>		
No. of directly addressable words	32k	128k
Add time, microseconds	2.4	6.25 (2 digits)
Hardware multiply/divide	Standard	No
Real-time clock or timer	Standard	Optional
<u>Main storage</u>		
Storage type	MOS	Core, MOS
Cycle/access time	0.96/0.16	0.98-1.6/0.5-0.8
Min/max capacity, words	32k/64k	512/8k
<u>I/O control</u>		
DMA	Yes	Standard
Maximum I/O rate, word/s	3072k bytes	250k
No. of external interrupt levels	16	1
<u>Communications</u>		
Asynchronous	Std, 110-9600 bps	Opt, 9600 bps
RJE terminals emulated	2780/3780	–
<u>Peripheral equipment</u>		
Floppy disk (diskette) drives	Opt, 315-630k bytes	243-972k bytes
Disk pack/cartridge drives	Cart, 10-20M bytes	Cart, 4.92-19.68M bytes
Drum/fixed head disk storage	Opt, 12.5-25M bytes	No
Serial printer	60-180 cps	100, 165 cps
Line printer	240-900 lpm	No
Data communication interface	110-9600 bps	To 9600 bps

	Manufacturer and Model	
	Computer Automation Naked Mini ESI-2 Series	Computer Automation Naked Mini 4 Family
Word length, bits	16 + 2	16
Software		
Compiler	FORTRAN, BASIC	FORTRAN, BASIC
Operating system	Batch, real-time	Batch, real-time
Language implemented in firmware	No multitasking	No
Price ($)		
CPU	2540 (2/10 Alpha) 2865 (2/20 Alpha)	995 (4/10 Alpha) 4080 (4/90 Alpha)
Central processor		
No. of directly addressable words	32k	64k
Add time, microseconds	4.12, 2.06	1.5-3.0
Hardware multiply/divide	Standard	Standard
Real-time clock or timer	Optional	Standard
Main storage		
Storage type	Core, MOS	Core, MOS
Cycle/access time	0.85-1.2/0.4-0.6	0.551-0.85/0.3-0.4
Min/max capacity, words	8k/512k	4k/64k
I/O control		
DMA	Standard	Optional
Maximum I/O rate, word/s	1M	115k
No. of external interrupt levels	3	4
Communications		
Asynchronous	Opt, 9600 bps	Opt, 50-19200 bps
RJE terminals emulated	–	–
Peripheral equipment		
Floppy disk (diskette) drives	243-972k bytes	(4) 243k-972k bytes
Disk pack/cartridge drives	Cartridge, 4.92-19.68M bytes	Both, 5-1200M bytes
Drum/fixed head disk storage	No	No
Serial printer	100, 165 cps	No
Line printer	No	60-165 lpm
Data communication interface	To 9600 bps	To 9600 bps

	Manufacturer and Model	
	Computer Automation Scout Naked Mini 4/04	Computer Automation Syfa System 200
Word length, bits	16	16
Software		
Compiler	FORTRAN IV, COBOL	SYBOL
Operating system	Real-time	Time-sharing
Language implemented in firmware	No	No
Price ($)		
CPU	1010 (32k byte RAM)	29950
Central processor		
No. of directly addressable words	64k	32k
Add time, microseconds	3.40	4.12, 2.06
Hardware multiply/divide	Standard	Standard
Real-time clock or timer	Standard	Optional
Main storage		
Storage type	MOS	MOS
Cycle/access time	1.0/0.786	0.7/0.5
Min/max capacity, words	16k/64k words	64k/64k bytes
I/O control		
DMA	Standard	Standard
Maximum I/O rate, word/s	3.8M	NA
No. of external interrupt levels	3	NA
Communications		
Asynchronous	Opt, 19.2k bps	Std, 9600 bps
RJE terminals emulated	No	IBM 3780
Peripheral equipment		
Floppy disk (diskette) drives	(1-4) 1M-4M bytes	No
Disk pack/cartridge drives	No	Both, (8) 1760M bytes
Drum/fixed head disk storage	No	No
Serial printer	-	150 cps
Line printer	Yes	Optional
Data communication interface	19.2k bytes	Yes

	Manufacturer and Model	
	Computer Automation Syfa System 300	Computer Automation Syfa System 1000
Word length, bits	16	16
<u>Software</u>		
Compiler	SYBOL	SYBOL
Operating system	Time-sharing	Time-sharing
Language implemented in firmware	No	No
<u>Price ($)</u>		
CPU	36000	102500
<u>Central processor</u>		
No. of directly addressable words	32k	32k
Add time, microseconds	4.12, 2.06	4.12, 2.06
Hardware multiply/divide	Standard	Standard
Real-time clock or timer	Optional	Optional
<u>Main storage</u>		
Storage type	MOS	MOS
Cycle/access time	0.7/0.5	0.7/0.5
Min/max capacity, words	64k/304k bytes	64k/304k bytes
<u>I/O control</u>		
DMA	Standard	Standard
Maximum I/O rate, word/s	NA	NA
No. of external interrupt levels	NA	NA
<u>Communications</u>		
Asynchronous	Std, 9600 bps	Std, 9600 bps
RJE terminals emulated	IBM 3780	IBM 3780, 3790
<u>Peripheral equipment</u>		
Floppy disk (diskette) drives	No	No
Disk pack/cartridge drives	Both, (8) 1760M bytes	Both, (8) 1760M bytes
Drum/fixed head disk storage	No	No
Serial printer	50 cps	Opt, 150 cps
Line printer	Optional	Std, 600 lpm
Data communication interface	Yes	Yes

	Manufacturer and Model Computer Designed Systems Adviser IV/700
Word length, bits	16 + 2
<u>Software</u>	
Compiler	PASCAL, COBOL, BASIC, FORTRAN
Operating system	Batch, real-time, multitask, interactive
Language implemented in firmware	Partially
<u>Price ($)</u>	
CPU	59000 (64k)
<u>Central processor</u>	
No. of directly addressable words	64k
Add time, microseconds	1.05
Hardware multiply/divide	Standard
Real-time clock or timer	Optional
<u>Main storage</u>	
Storage type	Core, MOS
Cycle/access time	0.50, 0.80/0.04
Min/max capacity, words	16k/512k
<u>I/O control</u>	
DMA	Standard
Maximum I/O rate, word/s	1.6M
No. of external interrupt levels	1-125
<u>Communications</u>	
Asynchronous	Opt, 9600 bps
RJE terminals emulated	2780/3780
<u>Peripheral equipment</u>	
Floppy disk (diskette) drives	No
Disk pack/cartridge drives	Both 2.4G bytes
Drum/fixed head disk storage	No
Serial printer	200 cps
Line printer	300-1200 lpm
Data communication interface	To 9600 bps

	Manufacturer and Model Computer Designed Systems Adviser IV/900
Word length, bits	32 + 4
<u>Software</u>	
Compiler	PASCAL, COBOL, BASIC, FORTRAN
Operating system	Batch, real-time, multitask, interactive
Language implemented in firmware	Partially
<u>Price ($)</u>	
CPU	32000 (16k bytes)
<u>Central processor</u>	
No. of directly addressable words	256k
Add time, microseconds	0.4
Hardware multiply/divide	Standard
Real-time clock or timer	Standard
<u>Main storage</u>	
Storage type	MOS
Cycle/access time	0.35, 0.68/0.03
Min/max capacity, words	32k/1024k
<u>I/O control</u>	
DMA	Standard
Maximum I/O rate, word/s	2.91M
No. of external interrupt levels	–
<u>Communications</u>	
Asynchronous	Opt, 9600 bps
RJE terminals emulated	2780/3780
<u>Peripheral equipment</u>	
Floppy disk (diskette) drives	No
Disk pack/cartridge drives	Both 4.8G bytes
Drum/fixed head disk storage	No
Serial printer	200 cps
Line printer	300-1200 lpm
Data communication interface	To 9600 bps

	Manufacturer and Model		
	Computer Hardware Inc 2130	Computer Hardware Inc 3230	Computer Hardware Inc 4210
Word length, bits	16	16	16
Software			
Compiler	COBOL, FORTRAN, RPG	COBOL, FORTRAN, RPG	FORTRAN
Operating system	Batch, time-sharing	Batch, time-sharing	Real-time
Language imp. firmware	No	No	No
Price ($)			
CPU	32000 (16k bytes)	15000 (16k bytes)	13200
Central processor			
No. directly addr. wds.	64k	64k	32k
Add time, microseconds	1.6	2.7	4.662
Hardware multiply/divide	Standard	Standard	Standard
Real-time clock or timer	Optional	Optional	Optional
Main storage			
Storage type	MOS, core	MOS	MOS
Cycle/access time	0.8/0.25	1.6/0.25	0.47/0.3
Min/max capacity, words	8k/2000k	8k/64k	4k/26k
I/O control			
DMA	Standard	Standard	Standard
Maximum I/O rate, word/s	1.25M	1.25M	-
No. ext. interrupt levels	8	8	8
Communications			
Asynchronous	Opt, 50-9600 bps	Opt, 50-9600 bps	Opt, 50-9600 bps
RJE terminals emulated	IBM 2780/3780	IBM 2780/3780	IBM 2780/3780
Peripheral equipment			
Floppy disk drives	No	No	Yes
Disk pack/cart. drives	Pack, 1600M bytes	Pack, 1600M bytes	No
Drum/fixed head disk storage	No	No	No
Serial printer	No	No	30-180 cps
Line printer	300, 600 lpm	300, 600 lpm	300 lpm
Data comm. interface	To 4800 bps sync	To 4800 bps sync	9600 bps

	Manufacturer and Model		
	Computer Hardware Inc 4250	Computer Hardware Inc 4800	Computer Talk Model 400
Word length, bits	16	16	16
<u>Software</u>			
Compiler	BASIC, COBOL, FORTRAN	BASIC, COBOL, FORTRAN	BASIC, FORTRAN, APL
Operating system	Real-time	Real-time	Real-time, batch, time-sharing
Language imp. firmware	No	No	Partially
<u>Price ($)</u>			
CPU	37800	8850	24950 (4k MOS)
<u>Central processor</u>			
No. directly addr. wds.	64k	32k	32k, 512k
Add time, microseconds	3.5	–	1.0
Hardware multiply/divide	Standard	Standard	Standard
Real-time clock or timer	Optional	Standard	Standard w/date
<u>Main storage</u>			
Storage type	MOS	Bipolar dynamic	MOS
Cycle/access time	0.47/0.3	–	0.5, 0.3/0.3, 0.15
Min/max capacity, words	4k/1024k	16k/128k	4k/512k
<u>I/O control</u>			
DMA	Standard	Standard	Standard
Maximum I/O rate, word/s	–	–	1M
No. ext. interrupt levels	16	7	1-256
<u>Communications</u>			
Asynchronous	Opt, 50-9600 bps	Std, 50-9600 bps	Opt, 50-9600 bps
RJE terminals emulated	IBM 2780/3780	IBM 2780/3780	Most RJE terminals
<u>Peripheral equipment</u>			
Floppy disk drives	Yes	1-4M bytes	110k-10240k bytes
Disk pack/cart. drives	Cart, 3M or 10M	No	Both, 1.2M-1G bytes
Drum/fixed head disk storage	No	No	Moving head 2.5M bytes
Serial printer	30-180 cps	No	10-200 cps
Line printer	300 lpm	84 lpm	220-600 lpm
Data comm. interface	9600 bps	19.2k bps	50-9600, 56k bps

	Manufacturer and Model		
	Computer Talk Model 407	Computer Talk Model 408	Computervision Corporation CGP-100
Wor ength, bits	16	16	16
<u>Software</u>			
Compiler	BASIC, FORTRAN, APL	BASIC, FORTRAN, APL	FORTRAN, TPL, PEP
Operating system	Batch, real-time, time-sharing	Batch, real-time, time-sharing	Multisharing, multitasking
Language imp. firmware	Partially	Partially	No
<u>Price ($)</u>			
CPU	31500 (4k MOS)	30500 (4k MOS)	Contact ventor
<u>Central processor</u>			
No. directly addr. wds.	32k, 512k	32k, 512k	32k
Add time, microseconds	1.0	1.0	0.9
Hardware multiply/divide	Standard	Standard	Standard
Real-time clock or timer	Std with date	Std with date	Standard
<u>Main storage</u>			
Storage type	MOS	MOS	MOS
Cycle/access time	0.5, 0.3/0.3, 0.15	0.5, 0.3/0.3, 0.15	0.7/0.4
Min/max capacity, words	4k/512k	4k/512k	32k/512k
<u>I/O control</u>			
DMA	Standard	Standard	Standard
Maximum I/O rate, word/s	1M	1M	0.7M
No. ext. interrupt levels	1-256	1-256	16
<u>Communications</u>			
Asynchronous	Opt, 50-9600 bps	Opt, 50-9600 bps	-
RJE terminals emulated	Most RJE terminals	Most RJE terminals	-
<u>Peripheral equipment</u>			
Floppy disk drives	110k bytes	110k-10240k bytes	256k-4M bytes
Disk pack/cart. drives	Both, 1.2M-1G bytes	Both, 1.2M-1G bytes	Pack, 1.2G bytes
Drum/fixed head disk storage	Moving head, 2.5M bytes	Moving head, 2.5M bytes	No
Serial printer	10-200 cps	10-200 cps	165 cps
Line printer	300 lpm	300 lpm	340 lpm
Data comm. interface	50-9600, 56 bps	50-9600, 56k	9600 bps

	Manufacturer and Model		
	Control Data Cyber 18 Series	Data General Eclipse C/150	Data General Eclipse C/350
Word length, bits	16 + 2	16 + 5	16 + 5
Software			
Compiler	FORTRAN, COBOL, RPG	COBOL, IDEA, RPG II, FORTRAN, PL/1	COBOL, IDEA, RPG II, FORTRAN, PL/1
Operating system	Batch, real- time, time-sharing	Batch, real-time, time-sharing	Batch, real-time, time-sharing
Language imp. firmware	No	No	No
Price ($)			
CPU	13700-15300	28500 (128k bytes)	49500 (128k bytes)
Central processor			
No. directly addr. wds.	64k	32k	32k
Add time, microseconds	0.95	0.6	0.6
Hardware multiply/divide	Standard	Standard	Standard
Real-time clock or timer	Standard	Standard	Standard
Main storage			
Storage type	MOS	Core, MOS	Core, MOS
Cycle/access time	0.75/0.3	0.8, 0.5, 0.7/0.4	0.8, 0.7/0.5
Min/max capacity, words	16k/256k bytes	64k/512k	32k/1024k
I/O control			
DMA	Standard	Standard	Standard
Maximum I/O rate, word/s	1.2M	1.25M	1.25M/5.0M
No. ext. interrupt levels	16	16	16
Communications			
Asynchronous	Opt, 9600 bps	Opt, 9600 bps	Opt, 9600 bps
RJE terminals emulated	2780/3780 HASP	2780/3780 HASP	2780/3780 HASP
Peripheral equipment			
Floppy disk drives	280k-560k bytes	315k-2.5M bytes	315k-2.5M bytes
Disk pack/cart. drives	Both, 4-1440M bytes	Pack & Cart, 10-1520M bytes	Pack & Cart, 10-1520M bytes
Drum/fixed head disk storage	No	Fixed head, 1-16M bytes	Fixed head, 1-16M bytes
Serial printer	180 cps	10-180 cps	10-180 cps
Line printer	300, 600, 900 lpm	240-900 lpm	240-900 lpm
Data comm. interface	Up to 9600 bps	56000 bps	56000 bps max

	Manufacturer and Model		
	Data General Eclipse M/600	Data General Eclipse S/130	Data General Eclipse S/140
Word length, bits	16 + 5	16 + 5	16 + 5
Software			
Compiler	COBOL, IDEA, RPG II, FORTRAN, PL/1	FORTRAN, BASIC, ALGOL, PL/1	COBOL, IDEA, RPG II, BASIC, FORTRAN
Operating system	Batch, real-time, time-sharing	Batch, real-time, time-sharing	Batch, real-time, time-sharing
Language imp. firmware	No	No	No
Price ($)			
CPU	80000 (256k bytes)	16500 (128k bytes)	16500 (128k bytes)
Central processor			
No. directly addr. wds.	32k	64k	32k
Add time, microseconds	0.6	0.6	0.2
Hardware multiply/divide	Standard	Standard	Standard
Real-time clock or timer	Standard	Standard	Standard
Main storage			
Storage type	Core, MOS	Core, MOS	MOS
Cycle/access time	0.8/0.5	0.8, 0.5, 0.7/0.4	0.2/0.4
Min/max capacity, words	32k/1024k	16k/512k	64k/512k
I/O control			
DMA	Standard	Standard	Standard
Maximum I/O rate, word/s	1.2M/5.0M	1.25M	1.25M
No. ext. interrupt levels	16	16	16
Communications			
Asynchronous	Opt, 9600 bps	Opt, 9600 bps	Opt, 9600 bps
RJE terminals emulated	2780/3780 HASP	2780/3780 HASP	2780/3780 HASP
Peripheral equipment			
Floppy disk drives	315k-2.5M bytes	315k-2.5M bytes	315k-2.5M bytes
Disk pack/cart. drives	Pack & cart, 10-6080M bytes	Pack & cart, 10-1520M bytes	Pack & cart, 10-1520M bytes
Drum/fixed head disk storage	Fixed head, 1-16M bytes	Fixed head, 1-16M bytes	Fixed head, 1-16M bytes
Serial printer	10-180 cps	10-180 cps	10-180 cps
Line printer	240-900 lpm	240-900 lpm	240-900 lpm
Data comm. interface	56000 bps max	56000 bps	56000 bps

	Manufacturer and Model		
	Data General NOVA 4C	Data General NOVA 4S	Data General NOVA 4X
Word length, bits	16	16	16
<u>Software</u>			
Compiler	BASIC, FORTRAN, ALGOL	BASIC, FORTRAN, ALGOL	BASIC, FORTRAN, ALGOL
Operating system	Real-time, RDOS, multitasking	Real-time, RDOS, multitasking	Real-time, RDOS, multitasking
Language imp. firmware	No	No	No
<u>Price ($)</u>			
CPU	2800 (32k bytes)	5800 (32k bytes)	10400 (128k bytes)
<u>Central processor</u>			
No. directly addr. wds.	1k	1k	1k
Add time, microseconds	0.2	0.2	0.2
Hardware multiply/divide	Optional	Optional	Optional
Real-time clock or timer	Optional	Standard	Standard
<u>Main storage</u>			
Storage type	MOS	MOS	MOS
Cycle/access time	0.40	–	–
Min/max capacity, words	16k/32k	16k/32k	16k/128k
<u>I/O control</u>			
DMA	Standard	Standard	Standard
Maximum I/O rate, word/s	1M	1M	1M
No. ext. interrupt levels	16	16	16
<u>Communications</u>			
Asynchronous	Opt, (128) 19 200 bps	Opt, (128) 19 200 bps	Opt, (128) 19 200 bps
RJE terminals emulated	2780/3780 HASP II	2780/3780 HASP II	2780/3780 HASP II
<u>Peripheral equipment</u>			
Floppy disk drives	Yes	Yes	Yes
Disk pack/cart. drives	Yes	Yes	Yes
Drum/fixed head disk storage	Yes	Yes	Yes
Serial printer	Yes	Yes	Yes
Line printer	Yes	Yes	Yes
Data comm. interface	Yes	Yes	

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	Manufacturer and Model		
	Data Ram BM-1	Data Ram BM-2	Digital Equipment PDP-11/03
Word length, bits	16	16	16
<u>Software</u>			
Compiler	NA	BASIC, FORTRAN	BASIC, FORTRAN
Operating system	Batch, real-time	Batch, real-time	Batch, real-time
Language imp. firmware	No	No	No
<u>Price ($)</u>			
CPU	8795 (64k byte mem. + 256k byte bulkcore)	11645 (64k byte mem. + 512k byte bulksemi)	1995 (8k MOS)
<u>Central processor</u>			
No. directly addr. wds.	128k	128k	32k
Add time, microseconds	3.5	3.5	3.5
Hardware multiply/divide	Optional	Optional	Optional
Real-time clock or timer	Optional	Optional	Optional
<u>Main storage</u>			
Storage type	Core, MOS	Core, MOS	Core, MOS
Cycle/access time	1.2/1.2	1.2/1.2	1.2
Min/max capacity, words	120k/120k bytes	8k/128k bytes	4k/32k
<u>I/O control</u>			
DMA	Standard	Standard	Standard
Maximum I/O rate, word/s	833k	833k	833k
No. ext. interrupt levels	Variable	Variable	Variable
<u>Communications</u>			
Asynchronous	–	–	Up to 9600 bps
RJE terminals emulated	–	–	Control Data, Univac
<u>Peripheral equipment</u>			
Floppy disk drives	No	No	256-512 bytes
Disk pack/cart. drives	No	No	No
Drum/fixed head disk storage	No	No	No
Serial printer	No	No	180 cps
Line printer	No	No	No
Data comm. interface	No	No	50-56000 bps

	Manufacturer and Model		
	Digital Equipment PDP-11/04	Digital Equipment PDP-11/34A	Digital Equipment PDP-11/35 & PDP-11/40
Word length, bits	16 + 2	16 + 2	16 + 2
Software			
Compiler	BASIC, FORTRAN, FOCAL	BASIC, FORTRAN, COBOL, FOCAL	BASIC, FORTRAN, COBOL, FOCOL
Operating system	Batch, real-time, time-sharing	Batch, real-time, time-sharing	Batch, real-time, time-sharing
Language imp. firmware	No	No	No
Price ($)			
CPU	3995 (16k MOS)	9050 (32k MOS)	19800
Central processor			
No. directly addr. wds.	32k	32k	32k
Add time, microseconds	3.17	2.03	1.07
Hardware multiply/divide	Optional	Optional	Optional
Real-time clock or timer	Standard	Standard	Optional
Main storage			
Storage type	Core, MOS	Core, MOS	Core
Cycle/access time	0.98, 0.725/0.51	0.98, 0.725/0.51	0.98/0.36
Min/max capacity, words	16k/32k	16k/124k	8k/124k
I/O control			
DMA	Standard	Standard	Standard
Maximum I/O rate, word/s	2048k	–	2M
No. ext. interrupt levels	Variable	Variable	Variable
Communications			
Asynchronous	Up to 9600 bps	Up to 9600 bps	Up to 9600 bps
RJE terminals emulated	Control Data, Univac	Control Data, Univac	Control Data, Univac
Peripheral equipment			
Floppy disk drives	256-512k bytes	256-512k bytes	256-512k bytes
Disk pack/cart. drives	Cart & pack, 2.5-1048M bytes	Cart & pack, 2.5-1408M bytes	Cart & pack, 2.5-1408M bytes
Drum/fixed head disk storage	Fixed head, 512k-8M bytes	Fixed head, 512k-8M bytes	Fixed head, 512k-8M bytes
Serial printer	30-180 cps	30-180 cps	30-180 cps
Line printer	230-1200 lpm	230-1200 lpm	230-1200 lpm
Data comm. interface	50-56000 bps	50-56000 bps	50-56000 bps

	Manufacturer and Model		
	Digital Equipment PDP-11/44	Digital Equipment PDP-11/60	Digital Equipment PDP-11/70
Word length, bits	16 + 2	16 + 2	16 + 2
<u>Software</u>			
Compiler	BASIC, FORTRAN, COBOL, APL, CORAL	BASIC, FORTRAN, COBOL	BASIC, FORTRAN, COBOL, FOCAL
Operating system	Batch, real-time, time-sharing	Real-time, time-sharing	Real-time, time-sharing
Language imp. firmware	No	No	No
<u>Price ($)</u>			
CPU	23900 (25k bytes)	35700 (32k core)	63000 (128k core)
<u>Central processor</u>			
No. directly addr. wds.	32k	32k	32k
Add time, microseconds	0.87	2.2	0.30-1.20
Hardware multiply/divide	Standard	Standard	Standard
Real-time clock or timer	Standard	Standard	Standard
<u>Main storage</u>			
Storage type	MOS, cache	Core, MOS	Core
Cycle/access time	0.48, 0.96/0.48	0.98/-	0.98/0.36
Min/max capacity, words	256k/1M bytes	32k/256k	64k/1024k
<u>I/O control</u>			
DMA	Standard	Standard	Standard
Maximum I/O rate, word/s	1M	-	2.9M
No. ext. interrupt levels	4	Variable	Variable
<u>Communications</u>			
Asynchronous	Up to 9600 bps	Up to 9600 bps	Up to 9600 bps
RJE terminals emulated	Control Data, Univac	Control Data, Univac	Control Data, Univac
<u>Peripheral equipment</u>			
Floppy disk drives	256-512k bytes	256-512k bytes	256-512k bytes
Disk pack/cart. drives	Both, 2.5-1408M bytes	Cart & pack, 2.5-1408M bytes	Cart & pack, 2.5-1408M bytes
Drum/fixed head disk storage	Fixed head, 512k-8M bytes	Fixed head, 512k-8M bytes	Fixed head, 512k-8M bytes
Serial printer	30-180 cps	30-180 cps	30-180 cps
Line printer	230-1200 lpm	230-1200 lpm	230-1200 lpm
Data comm. interface	50-56000 bps	50-56000 bps	50-56000 bps

	Manufacturer and Model		
	Digital Scientific 4030/40	Digital Scientific 5010	Digital Scientific 5020
Word length, bits	16 + 2	16 + 2	16 + 2
Software			
Compiler	COBOL, RPG II, APL, BASIC, FORTRAN	COBOL, RPG II, BASIC, FORTRAN	COBOL, BASIC, RPG II, FORTRAN, APL
Operating system	Real-time, time-sharing, multiprog	Batch	Batch, time-sharing
Language imp. firmware	Partially	No	No
Price ($)			
CPU	33850 (4030) 42285 (4040)	18000	24500
Central processor			
No. directly addr. wds.	64k	32k	32k
Add time, microseconds	2.9	1.44	1.44
Hardware multiply/divide	Standard	Standard	Standard
Real-time clock or timer	Optional	Optional	Optional
Main storage			
Storage type	Core	MOS	Core, MOS
Cycle/access time	0.9/0.5	0.5/0.3	0.9, 0.5/0.5, 0.3
Min/max capacity, words	8k/128k	4k/32k	8k/64k
I/O control			
DMA	Standard	Standard	Standard
Maximum I/O rate, word/s	1M	2M	1M-2M
No. ext. interrupt levels	6, 16	6	6
Communications			
Asynchronous	–	–	16
RJE terminals emulated	–	–	2780, 3780, 3740
Peripheral equipment			
Floppy disk drives	Yes	Yes	Yes
Disk pack/cart. drives	Both, 1-160M bytes	Cart, 1-5M	Both, 1-160M bytes
Drum/fixed head disk storage	Fixed, 1-2M bytes	No	Fixed, 1-2M bytes
Serial printer	180 cps	180 cps	180 cps
Line printer	300-1000 lpm	300, 600 lpm	300, 600 lpm
Data comm. interface	Up to 19200 bps	Up to 19200 bps	Up to 19300 bps

	Manufacturer and Model		
	Digital Scientific 5030	Digital Systems Galaxy/3	Digital Systems Galaxy/5
Word length, bits	16 + 2	8 to 20	8 to 20
Software			
Compiler	COBOL, RPG II, APL, BASIC, FORTRAN	RPG II, BASIC/5, PL/G, COBOL	RPG II, BASIC/5, PL/G, COBOL
Operating system	Batch, time-sharing, multi-programming	Timesharing	Timesharing
Language imp. firmware	Partially	Partially	Partially
Price ($)			
CPU	39600	28700	44930
Central processor			
No. directly addr. wds.	64k	128k	1024k
Add time, microseconds	1.44	0.30	0.30
Hardware multiply/divide	Standard	Standard	Standard
Real-time clock or timer	Optional	Standard	Standard
Main storage			
Storage type	Core, MOS	MOS	MOS
Cycle/access time	0.9, 0.5/0.5, 0.3	0.50/0.50	0.50/0.50
Min/max capacity, words	64k/1M	96k/128k bytes	128k/1024k bytes
I/O control			
DMA	Standard	Standard	Standard
Maximum I/O rate, word/s	1M-2M	200k	200k
No. ext. interrupt levels	6	15	60
Communications			
Asynchronous	32	Std, to 15000 bps	Std, to 9600 bps
RJE terminals emulated	2780, 3780, 3740	None	None
Peripheral equipment			
Floppy disk drives	Yes	No	No
Disk pack/cart. drives	Both, 1-160M bytes	Cart, 27M bytes/drive	Pack, 80M bytes/drive
Drum/fixed head disk storage	Fixed, 1-2M bytes	No	No
Serial printer	180 cps	No	No
Line printer	300, 600 lpm	300, 600, 900 lpm	300, 600, 900 lpm
Data comm. interface	Up to 19200 bps	110-9600 bps	110-9600 bps

	Manufacturer and Model		
	Dimis Inc Total 100 (70)	Dimis Inc Total 100 (30)	Four-Phase IV/40
Word length, bits	16	16	24
<u>Software</u>			
Compiler	FORTRAN	FORTRAN	COBOL, RPG
Operating system	Batch, real-time	Batch, real-time	IDOS, DOS
Language imp. firmware	No	No	No
<u>Price ($)</u>			
CPU	153000	98000	37440 (24k bytes)
<u>Central processor</u>			
No. directly addr. wds.	64k	64k	96k bytes
Add time, microseconds	0.2	0.3	16
Hardware multiply/divide	Standard	Standard	Standard
Real-time clock or timer	Standard	Standard	Standard
<u>Main storage</u>			
Storage type	MOS	MOS	MOS
Cycle/access time	250/250	250/250	2.0
Min/max capacity, words	128k/4096k	128k/512k	24k/96k bytes
<u>I/O control</u>			
DMA	Standard	Standard	No
Maximum I/O rate, word/s	4-8M	2-8M	125k
No. ext. interrupt levels	To 128	To 128	8
<u>Communications</u>			
Asynchronous	Std, to 9600 bps	Std, to 9600 bps	Up to 2400 bps
RJE terminals emulated	No	No	IBM 360/370
<u>Peripheral equipment</u>			
Floppy disk drives	Optional	Optional	354k bytes
Disk pack/cart. drives	Both, 4-200M bytes	Both, 4-200M bytes	Cart, 2.5-10M bytes
Drum/fixed head disk storage	Optional	Optional	10-20M bytes
Serial printer	Optional	Optional	55 cps
Line printer	600 lpm	600 lpm	120-1000 lpm
Data comm. interface	36k bytes	36k bytes	Up to 9600 bps

	Manufacturer and Model		
	Four-Phase IV/50	Four-Phase IV/90	Four-Phase IV/70
Word length, bits	24	24	24
Software			
Compiler	COBOL, RPG	COBOL, RPG	COBOL, RPG
Operating system	IDOS, DOS	IDOS, DOS	IDOS, DOS
Language imp. firmware	No	No	No
Price ($)			
CPU	69330	1930/month (42-mo. lease)	72315 (48k bytes)
Central processor			
No. directly addr. wds.	96k bytes	96k bytes	96k bytes
Add time, microseconds	16	12	16
Hardware multiply/divide	Standard	Standard	Standard
Real-time clock or timer	Standard	Standard	Standard
Main storage			
Storage type	MOS	MOS	MOS
Cycle/access time	2.0	0.8	2.0
Min/max capacity, words	24k/94k bytes	96k/384k bytes	24k/96k bytes
I/O control			
DMA	No	No	No
Maximum I/O rate, word/s	125k	125k	125k
No. ext. interrupt levels	8	8	8
Communications			
Asynchronous	Up to 2400 bps	Up to 2400 bps	Up to 2400 bps
RJE terminals emulated	IBM 360/370	IBM 360/370	IBM 360/370
Peripheral equipment			
Floppy disk drives	354k bytes	354k bytes	354k bytes
Disk pack/cart. drives	Cart, 2.5M-10M bytes	Pack and cart, 2.5M-270M bytes	Pack and cart, 2.5M-270M bytes
Drum/fixed head disk storage	12.5M bytes	10-20M bytes	10-20M bytes
Serial printer	55 cps	55 cps	55 cps
Line printer	120-1000 lpm	120-1000 lpm	120-1000 lpm
Data comm. interface	9600 bps	Up to 9600 bps	Up to 9600 bps

	Manufacturer and Model		
	Functional Automation F6401	Functional Automation F6420	Functional Automation F6440
Word length, bits	64	8, 32	8, 32
Software			
Compiler	None	FASL	FASL
Operating system	Real-time	Multiuser, real-time	Real-time
Language imp. firmware	Partially	Partially	Partially
Price ($)			
CPU	30902	20402	24280
Central processor			
No. directly addr. wds.	16384k bytes	16384k bytes	16384k bytes
Add time, microseconds	0.25	3.0	3.0
Hardware multiply/divide	No	No	No
Real-time clock or timer	No	Standard	Standard
Main storage			
Storage type	MOS	MOS	MOS
Cycle/access time	0.25/0.25	0.5/0.5	0.5/0.5
Min/max capacity, words	32k/2048k words	256k/16384k	256k/16384k
I/O control			
DMA	Standard	No	Standard
Maximum I/O rate, word/s	2.66M bps	8-9600 baud	1.25M bps
No. ext. interrupt levels	None	None	None
Communications			
Asynchronous	No	Std, 8-19200 bps	Std, 300/9600 bps
RJE terminals emulated	None	None	None
Peripheral equipment			
Floppy disk drives	-	-	-
Disk pack/cart. drives	-	-	Pack, 80/640M bps
Drum/fixed head disk storage	-	-	-
Serial printer	-	-	-
Line printer	-	300 lpm	-
Data comm. interface	-	(8) 19200 bps	300/9600 bps

	Manufacturer and Model		
	General Robotics Polaris	General Robotics Gemini	General Robotics Tristar
Word length, bits	16	16	16
<u>Software</u>			
Compiler	FORTRAN, BASIC, APL, DIBOL	FORTRAN, BASIC, APL, DIBOL	FORTRAN, BASIC, APL, DIBOL
Operating system	Batch, real-time, time-sharing	Batch, real-time, time-sharing	Batch, real-time, time-sharing
Language imp. firmware	No	No	No
<u>Price ($)</u>			
CPU	12000	9500	11000
<u>Central processor</u>			
No. directly addr. wds.	32k	32k	32k
Add time, microseconds	3.5	3.5	3.5
Hardware multiply/divide	Standard	Standard	Standard
Real-time clock or timer	Standard	Standard	Standard
<u>Main storage</u>			
Storage type	MOS	MOS	MOS
Cycle/access time	0.45/0.30	0.45/0.30	0.45/0.30
Min/max capacity, words	32k/32k	32k/32k	32k/32k
<u>I/O control</u>			
DMA	Standard	Standard	Standard
Maximum I/O rate, word/s	833k	833k	833k
No. ext. interrupt levels	Variable	Variable	Variable
<u>Communications</u>			
Asynchronous	Standard	Standard	Standard
RJE terminals emulated	IBM 2780	IBM 2780	IBM 2780
<u>Peripheral equipment</u>			
Floppy disk drives	1M byte	2.5M bytes	3.8M bytes
Disk pack/cart. drives	Optional	Optional	Optional
Drum/fixed head disk storage	No	No	No
Serial printer	110 cps	Optional	Optional
Line printer	No	No	No
Data comm. interface	Optional	Optional	Optional

	Manufacturer and Model		
	General Robotics Pegasus	Harris Slash 6	Harris 100
Word length, bits	16	24, 48	24, 48
Software			
Compiler	FORTRAN, BASIC, APL, DIBOL	FORTRAN IV, BASIC, FORGO, SNOBOL	FORTRAN IV & 77, APL, COBOL, RPG
Operating system	Batch, real-time, time-sharing	Real-time, batch	Real-time, batch, time-sharing
Language imp. firmware	No	No	No
Price ($)			
CPU	17000	17900 (48k bytes)	45000 (192k bytes)
Central processor			
No. directly addr. wds.	32k	96k bytes	96k bytes
Add time, microseconds	3.5	0.6	0.6
Hardware multiply/divide	Standard	Standard	Standard
Real-time clock or timer	Standard	Optional	Optional
Main storage			
Storage type	MOS	MOS	MOS
Cycle/access time	0.45/0.30	0.45/0.30	0.45/0.30
Min/max capacity, words	32k/32k	48k/768k bytes	192k/768k bytes
I/O control			
DMA	Standard	Optional	Optional
Maximum I/O rate, word/s	833k	To 19M bps	To 19M bps
No. ext. interrupt levels	Variable	8-24	8-24
Communications			
Asynchronous	Standard	-	Opt, 19.2k bps
RJE terminals emulated	IBM 2780	-	(See comments)
Peripheral equipment			
Floppy disk drives	Optional	No	No
Disk pack/cart. drives	Optional	Opt, 10.8M-4.8G	Opt, 40M-4.8G
Drum/fixed head disk storage	No	No	No
Serial printer	Optional	180 cps	180 cps
Line printer	No	240-900 lpm	240-900 lpm
Data comm. interface	Optional	56k bps	56k bps
Comments			RJE terminals emulated; 2780/3780, HASP workstation, UT-200, U-1004

	Manufacturer and Model		
	Harris 500	Harris 800	Hewlett-Packard General Systems Division HP 250
Word length, bits	24, 48	24, 48	16
Software			
Compiler	FORTRAN IV & 77, COBOL, RPG II	FORTRAN IV & 77, APL, COBOL, RPG II	Business BASIC
Operating system	Batch, real-time, time-sharing	Batch, real-time, time-sharing	Interactive, Interpretive
Language imp. firmware	No	No	See comments
Price ($)			
CPU	99500 (192k bytes)	155200 (384k bytes)	17000
Central processor			
No. directly addr. wds.	3072k bytes	3072k bytes	2k
Add time, microseconds	NA	NA	1.6
Hardware multiply/divide	Standard	Standard	No
Real-time clock or timer	Optional	Optional	No
Main storage			
Storage type	MOS	MOS	MOS
Cycle/access time	0.40/0.29	0.40/0.29	0.833
Min/max capacity, words	192k/3072k bytes	384k/3072k bytes	32k/64k bytes
I/O control			
DMA	Optional	Optional	Standard
Maximum I/O rate, word/s	To 19M bps	To 19M bps	1.2M bytes
No. ext. interrupt levels	16-48	16-72	2.0
Communications			
Asynchronous	Opt, 19.2k bps	Opt, 19.2k bps	Opt, 110-9600 bps
RJE terminals emulated	(See comments)	(See comments)	None
Peripheral equipment			
Floppy disk drives	No	No	3×3.6M bytes
Disk pack/cart. drives	Opt, 40M-4.8G bytes	Opt, 40M-4.8G bytes	Fixed, 10M bytes Cart, 10M bytes
Drum/fixed head disk storage	No	No	No
Serial printer	180 cps	180 cps	30, 180 cps
Line printer	240-900 lpm	240-900 lpm	400 lpm
Data comm. interface	56k bps	56k bps	Up to 9600 bps
Comments	RJE terminals emulated; 2780/3780, HASP workstation, UT-200, U-1004	RJE terminals emulated; 2780/3780, HASP workstation, UT-200, U-1004	

	Manufacturer and Model		
	Hewlett-Packard Gen. Systems Div. HP 300 Model A	Hewlett-Packard Gen. Systems Div. HP 300 Model B	Hewlett-Packard Gen. Systems HP 1000 M Series
Word length, bits	16	16	16 + 1
<u>Software</u>			
Compiler	BASIC, RPG	BASIC, RPG	FORTRAN, BASIC
Operating system	Batch, multi-task, multi-programming	Batch, multi-task, multi-programming	Real-time, DBMS, time-sharing
Language imp. firmware	Partially	Partially	No
<u>Price ($)</u>			
CPU	35000	45000	6950 (64k bytes)
<u>Central processor</u>			
No. directly addr. wds.	640M	64M	2k
Add time, microseconds	1.98	1.98	1.9
Hardware multiply/divide	Standard	Standard	Standard
Real-time clock or timer	Standard	Standard	Optional
<u>Main storage</u>			
Storage type	MOS	MOS	MOS
Cycle/access time	0.5/0.43	0.5/0.43	0.65
Min/max capacity, words	128k/512M bytes	128k/512M bytes	32k/1024k bytes
<u>I/O control</u>			
DMA	Standard	Standard	Optional
Maximum I/O rate, word/s	1.2M bytes	1.2M bytes	616k
No. ext. interrupt levels	0.5	0.5	50
<u>Communications</u>			
Asynchronous	Opt, to 9600 bps	Opt, to 9600 bps	Opt, to 2.5M bps
RJE terminals emulated	None	None	IBM 2780
<u>Peripheral equipment</u>			
Floppy disk drives	1M byte	1M byte	0.5-2M bytes
Disk pack/cart. drives	Opt, 80-480M bytes	Opt, 20-360M bytes	Both, to 960M bytes
Drum/fixed head disk storage	Std, 12M bytes	No	No
Serial printer	180 cps	180 cps	180 cps
Line printer	400 lpm	400 lpm	300-600 lpm
Data comm. interface	9600 bps	9600 bps	300-2.5M bps

	Manufacturer and Model		
	Hewlett-Packard HP 1000 E Series	Hewlett-Packard HP 1000 F Series	Hewlett-Packard HP 3000 Series 30
Word length, bits	16 + 1	16 + 1	16
<u>Software</u>			
Compiler	FORTRAN, BASIC	FORTRAN, BASIC	COBOL, RPG, SPL, BASIC, FORTRAN
Operating system	Real-time, DBMS, time-sharing	Real-time, DBMS, time-sharing	Batch, time-sharing transaction
Language imp. firmware	Partially	Partially	Partially
<u>Price ($)</u>			
CPU	8700 (64k bytes)	11750 (64k bytes)	28525 (256k bytes)
<u>Central processor</u>			
No. directly addr. wds.	2k	2k	32k (64k bytes)
Add time, microseconds	0.91	0.91	-
Hardware multiply/divide	Standard	Standard	Standard
Real-time clock or timer	Optional	Optional	Standard
<u>Main storage</u>			
Storage type	MOS	MOS	MOS
Cycle/access time	0.60, 0.35	0.35	0.86/0.43
Min/max capacity, words	32k/1024k bytes	32k/2048k bytes	256k/1024k bytes
<u>I/O control</u>			
DMA	Optional	Optional	Standard
Maximum I/O rate, word/s	1140k	1140k	1M
No. ext. interrupt levels	50	50	105
<u>Communications</u>			
Asynchronous	Opt, to 2.5M bps	Opt, to 2.5M bps	Std, (4) 9600 bps
RJE terminals emulated	IBM 2780	IBM 2780	2780/3780
<u>Peripheral equipment</u>			
Floppy disk drives	0.5-2M bytes	0.5-2M bytes	1.18M bytes
Disk pack/cart. drives	Both, 960M bytes bytes	Both, to 960M bytes	Cart, 20M bytes pack, 50, 120M bytes
Drum/fixed head disk storage	No	No	No
Serial printer	180 cps	180 cps	180 cps
Line printer	300-600 lpm	300-600 lpm	400 lpm
Data comm. interface	300-2.5M bps	300-2.5M bps	56k bps

	Manufacturer and Model		
	Hewlett-Packard HP 3000 Series 33	Hewlett-Packard HP 3000 Series III	Honeywell Level 6 Model 23
Word length, bits	16	16	16 + 2
Software			
Compiler	COBOL, RPG, SPL, BASIC, FORTRAN	COBOL, RPG, SPL, BASIC, FORTRAN	COBOL, FORTRAN, RPG
Operating system	Batch, time-sharing transaction	Batch, time-sharing transaction	Multiprogramming, trans processing
Language imp. firmware	Partially	Partially	No
Price ($)			
CPU	37275 (256k bytes)	75875 (256k bytes)	4800
Central processor			
No. directly addr. wds.	32k (64k bytes)	32k (64k bytes)	64k
Add time, microseconds	-	-	3.5
Hardware multiply/divide	Standard	Standard	Standard
Real-time clock or timer	Standard	Standard	Standard
Main storage			
Storage type	MOS	MOS	MOS
Cycle/access time	0.86/0.43	0.70/0.35	1.0
Min/max capacity, words	256k/1024k bytes	256k/2048k bytes	16k/64k words
I/O control			
DMA	Standard	Standard	Standard
Maximum I/O rate, word/s	1M	2.86M	900k words
No. ext. interrupt levels	105	124	64
Communications			
Asynchronous	Std, (8) 9600 bps	Std, (16) 2400 bps	Opt, 50-9600 bps
RJE terminals emulated	2780/3780	HASP2, JES2-3, ASP	2780/3780, HASP
Peripheral equipment			
Floppy disk drives	1.18M bytes	No	4×256/512k
Disk pack/cart. drives	Cart, 20M bytes pack, 50, 120M bytes	Pack, 50, 120M bytes	Cart, 4×26/80M bytes
Drum/fixed head disk storage	No	No	No
Serial printer	180 cps	180 cps	120, 160 cps
Line printer	400 lpm	400-1000 lpm	300, 600, 900 lpm
Data comm. interface	56k bps	56k bps	50-9600 bps

	Manufacturer and Model		
	Honeywell Level 6 Model 33	Honeywell Level 6 Model 43	Honeywell Level 6 Model 47
Word length, bits	16 + 2, + 6	16 + 2, + 6	16 + 2, + 6
<u>Software</u>			
Compiler	COBOL, FORTRAN, RPG	COBOL, FORTRAN, RPG	COBOL, FORTRAN, RPG
Operating system	Multiprog, trans, processing	Multiprog time-sharing	Multiprog time-sharing
Language imp. firmware	No	No	No
<u>Price ($)</u>			
CPU	7275	10325	22275
<u>Central processor</u>			
No. directly addr. wds.	64k	1024k	1024k
Add time, microseconds	1.9	1.0	1.0
Hardware multiply/divide	Standard	Standard	Standard
Real-time clock or timer	Standard	Standard	Standard
<u>Main storage</u>			
Storage type	MOS	MOS	MOS
Cycle/access time	0.65 or 0.55	0.65 or 0.55	0.65 or 0.55
Min/max capacity, words	16k/64k words	16k/1024k words	16k/1024k words
<u>I/O control</u>			
DMA	Standard	Standard	Standard
Maximum I/O rate, word/s	3M words	3M words	3M words
No. ext. interrupt levels	64	64	64
<u>Communications</u>			
Asynchronous	Opt, 50-19200 bps	Opt, 50-19200 bps	Opt, 50-19200 bps
RJE terminals emulated	2780/3780, HASP	2780/3780, HASP	2780/3780, HASP
<u>Peripheral equipment</u>			
Floppy disk drives	4×256/512k	4×256/512k	4×256/512k
Disk pack/cart. drives	Cart, 8×10/26/80M bytes pack, 8×67/256M bytes	Cart, 8×10/26/80M bytes pack, 8×67/256M bytes	Cart, 8×10/26/80M bytes pack, 8×67/256M bytes
Drum/fixed head disk storage	No	No	No
Serial printer	120, 160 cps	120, 160 cps	120, 160 cps
Line printer	300, 600, 900 lpm	300, 600, 900 lpm	300, 600, 900 lpm
Data comm. interface	50 bps/72k bytes	50 bps/72k bytes	50 bps/72k bytes

	Manufacturer and Model		
	Honeywell Level 6 Model 53	Honeywell Level 6 Model 57	IBM Series/1
Word length, bits	16 + 2, + 6	16 + 2, + 6	16
<u>Software</u>			
Compiler	COBOL, FORTRAN, RPG	COBOL, FORTRAN, RPG	FORTRAN, PL/1 COBOL
Operating system	Multiprog time-sharing	Multiprog time-sharing	Real-time multitasking
Language imp. firmware	No	No	Partially
<u>Price ($)</u>			
CPU	22175	46975	4360
<u>Central processor</u>			
No. directly addr. wds.	1024k	1024k	64k bytes
Add time, microseconds	0.7	0.7	NA
Hardware multiply/divide	Standard	Standard	No
Real-time clock or timer	Standard	Standard	Optional
<u>Main storage</u>			
Storage type	MOS	MOS	MOS
Cycle/access time	0.65 or 0.55	0.65 or 0.55	2.1, 0.8, 0.6
Min/max capacity, words	16k/1024k	16k/1024k	16k/256k bytes
<u>I/O control</u>			
DMA	Standard	Standard	Standard
Maximum I/O rate, word/s	3M words	3M words	–
No. ext. interrupt levels	64	64	256
<u>Communications</u>			
Asynchronous	Opt, 50-19200 bps	Opt, 50-19200 bps	Up to 9600 bps
RJE terminals emulated	2780/3780 HASP	2780/3780 HASP	2780/3780 HASP
<u>Peripheral equipment</u>			
Floppy disk drives	4×256/512k	4×256/512k	492-606k bytes
Disk pack/cart. drives	Cart, (8) 10/26/ 80M bytes pack, (8) 67/ 256M bytes	Cart, (8) 10/26/ 80M bytes pack, (8) 67/ 256M bytes	Nonremovable cart, 9.3-258M bytes
Drum/fixed head disk storage	No	No	No
Serial printer	120, 160 cps	120, 160 cps	120 cps
Line printer	300, 600, 900 lpm	300, 600, 900 lpm	80 to 414 lpm
Data comm. interface	50 bps/72k bytes	50 bps/72k bytes	To 9600 bps

	Manufacturer and Model		
	Jacquard J100	Jacquard J500	Melcom Business Systems Inc Mitsubishi 8038
Word length, bits	16	16	16
Software			
Compiler	BASIC, Data-Rite	BASIC, Data-Rite	BASIC, COBOL, RPG, Progress
Operating system	Time-sharing	Time-sharing	Batch, real-time, multiuser
Language imp. firmware	No	No	No
Price ($)			
CPU	19900	10200	43000
Central processor			
No. directly addr. wds.	256	256	64k bytes
Add time, microseconds	8.0	5.28	37.75 (5 digits)
Hardware multiply/divide	No	No	Standard
Real-time clock or timer	Standard	Standard	Standard
Main storage			
Storage type	MOS	MOS	MOS
Cycle/access time	1.5/3.0	0.50	0.6/0.26
Min/max capacity, words	48k/64k	64k/64k	128k/512k bytes
I/O control			
DMA	Standard	Standard	Std, high-speed
Maximum I/O rate, word/s	500k	750k	3.3M bps
No. ext. interrupt levels	1	1	1
Communications			
Asynchronous	Opt, to 4800 bps	Std, to 9600 bps	Opt, 300-9600 bps
RJE terminals emulated	2780/3780	2780/3780	-
Peripheral equipment			
Floppy disk drives	(2) 256k bytes	(2) 256, 512k bytes	256k-2M bytes
Disk pack/cart. drives	Both, 12-320M bytes	Cart, 12-96M bytes	Both, 10-40M bytes
Drum/fixed head disk storage	No	No	No
Serial printer	45 cps	45 cps	200 cps
Line printer	300 lpm	300 lpm, 150 cps	110/600 lpm
Data comm. interface	Up to 4800 bps	Up to 9600 bps	300-19200 bps

	Manufacturer and Model		
	Microdata Reality Series 2000	Microdata Reality Series 4000	Microdata Reality Series 6000
Word length, bits	16	16	16
Software			
Compiler	ENGLISH, DATA/ BASIC, PROC	ENGLISH, DATA/ BASIC, PROC	ENGLISH, DATA/ BASIC, PROC
Operating system	Interactive, multiuser	Interactive, multiuser	Interactive, multiuser
Language imp. firmware	Partially	Partially	Partially
Price ($)			
CPU	32500	38550	61250
Central processor			
No. directly addr. wds.	58k bytes	58k bytes	122k bytes
Add time, microseconds	-	-	-
Hardware multiply/divide	Standard	Standard	Standard
Real-time clock or timer	No	No	No
Main storage			
Storage type	Core	Core	Core, MOS
Cycle/access time	1.0	1.0	1.0, 0.8
Min/max capacity, words	16k/64k bytes	16k/64k bytes	32k/128k bytes
I/O control			
DMA	Standard	Standard	Standard
Maximum I/O rate, word/s	40000 bytes	40000 bytes	40000 bytes
No. ext. interrupt levels	-	-	-
Communications			
Asynchronous	No	No	No
RJE terminals emulated	HASP 360/370	HASP 360/370	HASP most IBM
Peripheral equipment			
Floppy disk drives	No	No	No
Disk pack/cart. drives	Cart, to 20M bytes	Cart, to 40M bytes	Cart, to 40M bytes
Drum/fixed head disk storage	No	Fixed to 50M bytes	Fixed to 200M bytes
Serial printer	120-165 cps	120-165 cps	120-165 cps
Line printer	150, 300, 600 lpm	150, 300, 600 lpm	150, 300, 600 lpm
Data comm. interface	To 9600 bps	To 9600 bps	To 9600 bps

Manufacturer and Model			
	Microdata Reality Series 8000	Modular Computer Systems Inc Classic 7810/3140	Modular Computer Systems Inc Classic 7830/7835
Word length, bits	16	16	16
Software			
Compiler	ENGLISH, DATA/ BASIC, PROC	COBOL, FORTRAN, CORAL 66, TOTAL	COBOL, FORTRAN, CORAL 66, TOTAL
Operating system	Interactive multiuser	Batch, real-time, time-sharing	Batch, real-time, time-sharing
Language imp. firmware	Partially	No	No
Price ($)			
CPU	84975	8150	23800/29500
Central processor			
No. directly addr. wds.	504k bytes	128k bytes	2048k bytes
Add time, microseconds	–	0.90	0.30
Hardware multiply/divide	Standard	Standard	Standard
Real-time clock or timer	No	Standard	Standard
Main storage			
Storage type	Core, MOS	MOS	MOS
Cycle/access time	1.0, 0.8	0.6/0.6	0.125/0.250
Min/max capacity, words	128k/512k bytes	64k/128k bytes	128k/2048k bytes
I/O control			
DMA	Standard	Standard	Standard
Maximum I/O rate, word/s	40000 bytes	500k bytes	5124.8k bytes
No. ext. interrupt levels	–	Up to 128	Up to 128
Communications			
Asynchronous	No	Opt, 50-19.2k bps	Opt, 50-19.2k bps
RJE terminals emulated	HASP 360/370	HASP 2780/3780	HASP 2780/3780
Peripheral equipment			
Floppy disk drives	No	315-630k bytes	315-630k bytes
Disk pack/cart. drives	Cart, to 40M bytes	Both, 2.5-256M bytes	Both, 2.5-256M bytes
Drum/fixed head disk storage	Fixed to 514M bytes	Fixed, (3) 0.5-2M bytes	Fixed, (3) 0.5-2M bytes
Serial printer	120-165 cps	(4) 30-440 cps	(4) 30-440 cps
Line printer	150, 300, 600 lpm	(5) 280-1000 lpm	(5) 280-1000 lpm
Data comm. interface	To 9600 bps	50-2000k bps	50-200k bps

	Manufacturer and Model		
	Modular Computer Systems Inc Classic 7860	Modular Computer Systems Inc Classic 7870	Modular Computer Systems Inc Modcomp II
Word length, bits	16	16	16 + 1
<u>Software</u>			
Compiler	COBOL, FORTRAN, CORAL 66, TOTAL	COBOL, FORTRAN, CORAL 66, TOTAL	COBOL, FORTRAN CORAL 66, TOTAL
Operating system	Batch, real-time, time-sharing	Batch, real-time, time-sharing	Batch, real-time, time-sharing
Language imp. firmware	No	No	No
<u>Price ($)</u>			
CPU	38150	61500	13400 (64k bytes)
<u>Central processor</u>			
No. directly addr. wds.	8192k bytes	8192k bytes	128k bytes
Add time, microseconds	0.20	0.20	0.8
Hardware multiply/divide	Standard	Standard	Standard
Real-time clock or timer	Standard	Standard	Optional
<u>Main storage</u>			
Storage type	Core, MOS	MOS	Core
Cycle/access time	0.125/0.250	0.125/0.250	0.8/0.4
Min/max capacity, words	128k/4096k bytes	512k/4096k bytes	32k/128k
<u>I/O control</u>			
DMA	Standard	Standard	Standard
Maximum I/O rate, word/s	To 96k bytes	To 96k bytes	3.86M bytes
No. ext. interrupt levels	Up to 128	Up to 128	Up to 128
<u>Communications</u>			
Asynchronous	Opt, 50-19.2k bps	Opt, 50-10.2k bps	-
RJE terminals emulated	HASP 2780/3780	HASP 2780/3780	-
<u>Peripheral equipment</u>			
Floppy disk drives	615-630k bytes	615-630k bytes	615-630k bytes
Disk pack/cart. drives	Both, 2.5-256M bytes	Both, 2.5-256M bytes	Both, 2.5-256M bytes
Drum/fixed head disk storage	Fixed (3) 0.5-2M bytes	Fixed, (3) 0.5-2M bytes	Fixed, (3) 0.5-2M bytes
Serial printer	(4) 30-440 cps	(4) 30-440 cps	(4) 30-440 cps
Line printer	(5) 280-1000 lpm	(5) 280-1000 lpm	(5) 280-1000 lpm
Data comm. interface	50-200k bps	50-200k bps	50-200k bps

	Manufacturer and Model		
	Modular Computer Systems Inc Modcomp IV/35	Mylee Digital Sciences 3000	Nanodata QM/1
Word length, bits	16 + 1	16	18 + 2
Software			
Compiler	COBOL, FORTRAN, CORAL 66, TOTAL	ACE	PASCAL, APL/SV
Operating system	Batch, real-time, time-sharing	Real-time	(See comments)
Language imp. firmware	No	Partially	Yes
Price ($)			
CPU	48200 (128k bytes)	28995 (56k bytes)	176000
Central processor			
No. directly addr. wds.	128k bytes	28k	256k
Add time, microseconds	0.56	20	0.75
Hardware multiply/divide	Standard	Standard	Standard
Real-time clock or timer	Standard	No	Optional
Main storage			
Storage type	Core	MOS	Core
Cycle/access time	0.5/0.4	0.8	0.75-125/0.3
Min/max capacity, words	64k/1024k	12k/143k	16k/1024k
I/O control			
DMA	Standard	Standard	Optional
Maximum I/O rate, word/s	7M bytes	1M	1M
No. ext. interrupt levels	Up to 128	1-18	2048
Communications			
Asynchronous	-	Opt, 1200 bps	Optional
RJE terminals emulated	-	2780/3780	IBM 360/370, 7094; UNIVAC 1106; DEC11/05, 11/04; DG NOVA; CDC 160A, DELCO 352, RCA 234SCP, UYK-7-20 and microprocessor
Peripheral equipment			
Floppy disk drives	615-630k bytes	Yes	No
Disk pack/cart. drives	Both, 2.5-256M bytes	Cart, 16-64M bytes	Both, 12-60M bytes
Drum/fixed head disk storage	Fixed (3) 0.5-2M bytes	No	No
Serial printer	(4) 30-440 cps	165 cps	200-1000 cps
Line printer	(5) 280-1000 lpm	300 lpm	600-1250 lpm
Data comm. interface	50-200k bps	9600 bps	Up to 50k bps
Comments			Emulation lab software provides both vert and horiz control store

Manufacturer and Model

	NCR 499	NCR 8130	NCR 8150
Word length, bits	16 + 1	16 + 2	16 + 2
Software			
Compiler	No	COBOL, BASIC	COBOL, BASIC
Operating system	No	Interactive	Interactive
Language imp. firmware			
Price ($)			
CPU	17900 (12k bytes)	10700	18300
Central processor			
No. directly addr. wds.	–	32k	32k
Add time, microseconds	1.7 ms	–	–
Hardware multiply/divide	Standard	No	No
Real-time clock or timer	No	Optional	Optional
Main storage			
Storage type	Core	MOS	MOS
Cycle/access time	1.2/0.65	0.6	0.6
Min/max capacity, words	12k/32k	48k/64k	48k/256k bytes
I/O control			
DMA	Standard	Standard	Standard
Maximum I/O rate, word/s	833k	866k	866k
No. ext. interrupt levels	8	16	16
Communications			
Asynchronous	Opt, 300-1800 bps	No	No
RJE terminals emulated	IBM 2780/3780	–	–
Peripheral equipment			
Floppy disk drives	No	512k-4096k bytes	250k bytes
Disk pack/cart. drives	Cart, 4.9-9.8M bytes	No	5-40M bytes
Drum/fixed head disk storage	No	No	No
Serial printer	75, 130 cps	110 cps	110 cps
Line printer	55-300 lpm	50-200 lpm	50-200 lpm
Data comm. interface	300-9600 bps	To 9600 bps	To 9600 bps

	Manufacturer and Model		
	NCR 8200	NCR 8231	NCR 8251
Word length, bits	16 + 2	16 + 2	16 + 2
<u>Software</u>			
Compiler	NEAT/3, COBOL	NEAT/3, COBOL	NEAT/3, COBOL
Operating system	Batch, multiprog	Batch, multiprog	Batch, multiprog
Language imp. firmware	No	No	No
<u>Price ($)</u>			
CPU	Available only used	27925	29925
<u>Central processor</u>			
No. directly addr. wds.	–	64k	–
Add time, microseconds	24 (8 digits)	–	–
Hardware multiply/divide	Standard	Standard	Standard
Real-time clock or timer	No	No	No
<u>Main storage</u>			
Storage type	Core	MOS	MOS
Cycle/access time	1.2/0.65	0.8	0.8
Min/max capacity, words	32k/128k bytes	64k/96k bytes	64k/512k bytes
<u>I/O control</u>			
DMA	Standard	Standard	Standard
Maximum I/O rate, word/s	833k	833k	833k
No. ext. interrupt levels	8	8	8
<u>Communications</u>			
Asynchronous	Opt to 9600 bps	Opt to 9600 bps	250
RJE terminals emulated	IBM 2780	IBM 2780	IBM 2780
<u>Peripheral equipment</u>			
Floppy disk drives	No	250k-1024k bytes	250k-1024k bytes
Disk pack/cart. drives	Cart, to 39.2M bytes	Cart, to 39.2M	Cart, to 80M bytes
Drum/fixed head disk storage	No	No	No
Serial printer	50, 70, 125 cps	173 cps	173 cps
Line printer	(See comments)	100-300 lpm	100-300 lpm
Data comm. interface	1200, 9600 bps	1200, 9600 bps	1200, 9600 bps
<u>Comments</u>	Line printers: 50, 70, and 125 lpm matrix; 200, 300, and 600 lpm band.		

	Manufacturer and Model		
	NCR 8270	NCR 8271	New England Digital Able/40
Word length, bits	16 + 2	16 + 2	16
Software			
Compiler	NEAT/3, COBOL	NEAT/3, COBOL	XPL, PASCAL, BASIC
Operating system	Batch, multiprog	Batch, multiprog	Real-time
Language imp. firmware	No	No	No
Price ($)			
CPU	21555	77812	7950
Central processor			
No. directly addr. wds.	–	–	64k
Add time, microseconds	–	–	0.25
Hardware multiply/divide	Standard	Standard	Optional
Real-time clock or timer	No	No	Standard
Main storage			
Storage type	MOS	MOS	Static MOS
Cycle/access time	0.8	0.8	0.5(avg)/0.5(avg)
Min/max capacity, words	64k/512k	96k/512k	16k/64k
I/O control			
DMA	Standard	Standard	Optional
Maximum I/O rate, word/s	833k	833k	2M
No. ext. interrupt levels	8	8	12
Communications			
Asynchronous	Opt, to 9600 bps	Opt to 9600 bps	300-38.4k bps
RJE terminals emulated	IBM 2780	IBM 2780	IBM 2780
Peripheral equipment			
Floppy disk drives	243-486k	243-486k	180k
Disk pack/cart. drives	54M-324M	Fixed & removable 20M-364M	No
Drum/fixed head disk storage	No		No
Serial printer	173 cps	173 cps	30, 120 cps
Line printer	50-900 lpm	200-900 lpm	300 lpm
Data comm. interface	1200-9600 bps	Up to 9600 bps	300-38400 bps

	Manufacturer and Model		
	New England Digital Able/60	Northrop Data Systems BDS Series 500	Northrop Data Systems BDS Series 1000
Word length, bits	16	Variable 8-32	Variable 8-32
<u>Software</u>			
Compiler	XPL, PASCAL, BASIC	–	–
Operating system	Real-time	Real-time	Real-time
Language imp. firmware	No	Partially	Partially
<u>Price ($)</u>			
CPU	9650	29500	34920
<u>Central processor</u>			
No. directly addr. wds.	64k	24k	24k
Add time, microseconds	0.25	9.68 (7 digits)	9.68 (7 digits)
Hardware multiply/divide	Optional	Standard	Standard
Real-time clock or timer	Standard	No	No
<u>Main storage</u>			
Storage type	Static MOS	Core	Core
Cycle/access time	0.5(avg)/0.5(avg)	1.0/NA	1.0/NA
Min/max capacity, words	16k/64k	24k/32k	24k/32k
<u>I/O control</u>			
DMA	Optional	Standard	Standard
Maximum I/O rate, word/s	2M	1M	1M
No. ext. interrupt levels	12	2, 128	2, 128
<u>Communications</u>			
Asynchronous	300-38.4k bps	Std, 200 bps	Std, 1200 bps
RJE terminals emulated	IBM 2780	–	–
<u>Peripheral equipment</u>			
Floppy disk drives	1.2M bytes	No	No
Disk pack/cart. drives	24M bytes	5M bytes, 10M bytes	10M bytes
Drum/fixed head disk storage	No	No	No
Serial printer	30, 120 cps	Opt, 100 cps	Opt, 100 cps
Line printer	300 lpm	150 lpm	150 lpm
Data comm. interface	300-38400 bps	1200 bps	1200 bps

	Manufacturer and Model		
	Northrop Data Systems BDS Series 2000	Northrop Data Systems BDS Series 4000	Olivetti BCS 3030
Word length, bits	Variable	16	16
Software			
Compiler	–	BASIC	Mini PL/1, RPG II
Operating system	Real-time	Reality, oper sys; virtual, engg, rpt	Interactive, batch
Language imp. firmware	Partially	Partially	No
Price ($)			
CPU	40355	52295	11000
Central processor			
No. directly addr. wds.	32k	64k	3500
Add time, microseconds	9.68 (7 digits)	9.68 (7 digits)	–
Hardware multiply/divide	Standard	Standard	–
Real-time clock or timer	No	No	No
Main storage			
Storage type	Core	MOS	MOS
Cycle/access time	1.0/NA	1.0/NA	–
Min/max capacity, words	32k/32k	64k/512k	40k/56k bytes
I/O control			
DMA	Standard	Standard	Standard
Maximum I/O rate, word/s	1M	1M	–
No. ext. interrupt levels	2, 128	2, 128	–
Communications			
Asynchronous	Std, 1200 bps	Opt, 9600 pbs	No
RJE terminals emulated	–	IBM 2780	None
Peripheral equipment			
Floppy disk drives	No	No	256-1024k
Disk pack/cart. drives	20M bytes, 40M bytes	20M bytes, 500M bytes	Cart, 10-20M bytes, nonremov 2.5-20M bytes
Drum/fixed head disk storage	No	No	No
Serial printer	Opt, 100 cps	Opt, 100 cps	90-175 cps
Line printer	150 lpm	150 lpm	300-600 lpm
Data comm. interface	1200 bps	9600 bps	To 9600 bps

	Manufacturer and Model		
	Perkin-Elmer Sixteen 10	Perkin-Elmer Sixteen 20	Perkin-Elmer Sixteen 30
Word length, bits	16 + 1	16 + 1	16 + 6
<u>Software</u>			
Compiler	BASIC, extended FORTRAN IV	BASIC, extended FORTRAN IV	BASIC, extended FORTRAN IV
Operating system	Batch, real-time, multi-tasking	Batch, real-time, multi-tasking	Batch, real-time, multi-tasking
Language imp. firmware	No	No	No
<u>Price ($)</u>			
CPU	5400 (8k words)	9000 (16k words)	11500 (16k words)
<u>Central processor</u>			
No. directly addr. wds.	32k	32k	32k
Add time, microseconds	1.0	0.825	0.750
Hardware multiply/divide	Optional	Optional	Standard
Real-time clock or timer	Standard	Standard	Standard
<u>Main storage</u>			
Storage type	MOS	MOS	MOS
Cycle/access time	1.0/NA	0.825/NA	0.750/NA
Min/max capacity, words	8k/32k	16k/131k	16k/131k
<u>I/O control</u>			
DMA	Standard	Standard	Standard
Maximum I/O rate, word/s	1M	1.21M	1.33M
No. ext. interrupt levels	1-255	1-255	1-255
<u>Communications</u>			
Asynchronous	Std to 9600 bps	Std to 9600 bps	Std to 9600 bps
RJE terminals emulated	IBM 2780/3780	IBM 2780/3780	IBM 2780/3780
<u>Peripheral equipment</u>			
Floppy disk drives	Yes 1-4	Yes 1-4	Yes 1-4
Disk pack/cart. drives	Both, 10-4800M bytes	Both, 10-4800M bytes	Both, 10-4800M bytes
Drum/fixed head disk storage	No	No	No
Serial printer	Yes 30-180 cps	Yes 30-180 cps	Yes 30-180 cps
Line printer	Yes 300-600 lpm	Yes 300-600 lpm	Yes 300-600 lpm
Data comm. interface	Yes, to 19.2k bps	Yes, to 19.2k bps	Yes, to 19.2k bps

	Manufacturer and Model		
	Perkin-Elmer Model 7/32 CII	Perkin-Elmer Model 8/32	Perkin-Elmer Model 3220
Word length, bits	32 + 2	32 + 2	32 + 7
Software			
Compiler	BASIC, extended FORTRAN IV	BASIC, COBOL, RPG II, FORTRAN IV	BASIC, COBOL, RPG II, FORTRAN IV
Operating system	Batch, real-time, multi-tasking	Batch, real-time, multi-tasking	Batch, real-time, multi-tasking
Language imp. firmware	No	No	No
Price ($)			
CPU	12045 (32k words)	51900 (65k words)	33500 (131k words)
Central processor			
No. directly addr. wds.	500k	500k	500k
Add time, microseconds	–	–	–
Hardware multiply/divide	Standard	Standard	Standard
Real-time clock or timer	Standard	Optional	Standard
Main storage			
Storage type	Core	Core	MOS
Cycle/access time	0.750/NA	0.3/NA	0.34/NA
Min/max capacity, words	32k/500k	62k/500k	131k/500k
I/O control			
DMA	Standard	Standard	Standard
Maximum I/O rate, word/s	1M	1.5M	2M
No. ext. interrupt levels	1-1023	1-1023	1-1023
Communications			
Asynchronous	–	–	–
RJE terminals emulated	–	–	–
Peripheral equipment			
Floppy disk drives	No	No	No
Disk pack/cart. drives	Both, 10-8400M bytes	Both, 10-8400M bytes	Both, 10-8400M bytes
Drum/fixed head disk storage	No	No	No
Serial printer	Yes, 30-180 cps	Yes, 30-180 cps	Yes, 30-180 cps
Line printer	Yes, 300-600 lpm	Yes, 300-600 lpm	Yes, 300-600 lpm
Data comm. interface	Yes, to 19.2k bps	Yes, to 19.2k bps	Yes, to 19.2k bps

	Manufacturer and Model		
	Perkin-Elmer Model 3240	Computer Corp Point 4	Prime 450
Word length, bits	32 + 7	16	16, 32
<u>Software</u>			
Compiler	BASIC, COBOL, RPG II, FORTRAN IV	Business BASIC	BASIC, FORTRAN, COBOL, RPG II
Operating system	Batch, real-time, multi-tasking	Real-time, interactive, time-sharing	Multiuser, virtual memory
Language imp. firmware	No	No	Partially
<u>Price ($)</u>			
CPU	85000 (131k words)	5540	65000-73000
<u>Central processor</u>			
No. directly addr. wds.	8M	64k	64k
Add time, microseconds	–	0.40	1.1
Hardware multiply/divide	Standard	Optional	Standard
Real-time clock or timer	Standard	No	Standard
<u>Main storage</u>			
Storage type	MOS	MOS	MOS, bipolar cache
Cycle/access time	0.25/NA	0.4/0.2	0.75/0.54
Min/max capacity, words	131k/8M	32k/64k	256k/1024k bytes
<u>I/O control</u>			
DMA	Standard	Std & high-speed	Standard
Maximum I/O rate, word/s	10M	1.1M	2.5M bytes
No. ext. interrupt levels	1-1023	1-16	64
<u>Communications</u>			
Asynchronous	–	Std, 19200 bps	Std to 9600 bps
RJE terminals emulated	–	IBM 2780/3780	HASP, 2780/3780
<u>Peripheral equipment</u>			
Floppy disk drives	No	No	512k-2M bytes
Disk pack/cart. drives	Both, 10-38, 400M bytes	No	Both, 12-2400M bytes
Drum/fixed head disk storage	No	No	Fixed head, 512k-1M bytes
Serial printer	Yes, 30-180 cps	No	300 lpm
Line printer	Yes, 300-600 lpm	No	To 1000 lpm
Data comm. interface	Yes, to 19.2 bps	56k bps	To 56k bps

	Manufacturer and Model		
	Prime 550	Prime 650	Prime 750
Word length, bits	16, 32	16, 32	16, 32
Software			
Compiler	BASIC, FORTRAN, COBOL, RPG II	BASIC, FORTRAN, COBOL, RPG II	BASIC, FORTRAN, COBOL, RPG II
Operating system	Multiuser, virtual memory	Multiuser, virtual memory	Multiuser, virtual memory
Language imp. firmware	Partially	Partially	Partially
Price ($)			
CPU	80000	105000	130000-149000
Central processor			
No. directly addr. wds.	64k	64k	64k
Add time, microseconds	1.1	1.1	0.5
Hardware multiply/divide	Standard	Standard	Standard
Real-time clock or timer	Standard	Standard	Standard
Main storage			
Storage type	MOS, bipolar cache	MOS, bipolar cache	MOS, bipolar cache
Cycle/access time	0.75/0.54	0.75/0.54	0.75/0.54
Min/max capacity, words	512k/2048k bytes	512k/4096k bytes	512k/8192k bytes
I/O control			
DMA	Standard	Standard	Standard
Maximum I/O rate, word/s	2.5M bytes	2.5M bytes	8M bytes
No. ext. interrupt levels	64	64	64
Communications			
Asynchronous	Std, to 9600 bps	Std, to 9600 bps	Std, to 9600 bps
RJE terminals emulated	HASP, 2780/3780	HASP, 2780/3780	HASP, 2780/3780
Peripheral equipment			
Floppy disk drives	512k-2M bytes	512k-2M bytes	512k-2M bytes
Disk pack/cart. drives	Both, 12-2400M bytes	Both, 12-2400M bytes	Both, 12-2400M bytes
Drum/fixed head disk storage	Fixed head, 512k-1M bytes	Fixed head, 512k-1M bytes	Fixed head, 512k-1M bytes
Serial printer	300 lpm	300 lpm	300 lpm
Line printer	To 1000 bps	To 1000 bps	To 1000 bps
Data comm. interface	To 56k bps	To 56k bps	To 56k bps

	Manufacturer and Model	
	Raytheon RDS-500	Raytheon RDS-7500
Word length, bits	16 + 2	16 + 2
<u>Software</u>		
Compiler	FORTRAN	FORTRAN
Operating system	Batch, real-time, multi-programming	Batch, real-time, multi-programming
Language imp. firmware	No	No
<u>Price ($)</u>		
CPU	19800 (32k core)	17100 (32k MOS)
<u>Central processor</u>		
No. directly addr. wds.	64k	64k
Add time, microseconds	1.4	1.4
Hardware multiply/divide	Standard	Standard
Real-time clock or timer	Optional	Optional
<u>Main storage</u>		
Storage type	Core or MOS	MOS
Cycle/access time	0.70/0.45	0.70/0.45
Min/max capacity, words	16k/64k	32k/128k
<u>I/O control</u>		
DMA	Standard	Standard
Maximum I/O rate, word/s	2M	2M
No. ext. interrupt levels	16	16
<u>Communications</u>		
Asynchronous	–	–
RJE terminals emulated	–	–
<u>Peripheral equipment</u>		
Floppy disk drives	No	No
Disk pack/cart. drives	Both, 2.56-1200M bytes	Both, 2.56-1200M bytes
Drum/fixed head disk storage	Fixed head, 770k-3.08M bytes	Fixed head, 770k-3.08M bytes
Serial printer	10-165 cps	10-165 cps
Line printer	300-1250 lpm	300-1250 lpm
Data comm. interface	14.2k bps	19.2k bps

	Manufacturer and Model		
	Rolm 1602B (AN/UYK-19)	Rolm 1603A (AN/UYK-12)	Rolm 1606 (AN/UYK-19)
Word length, bits	16	16	16
Software			
Compiler	ALGOL, BASIC, FORTRAN	ALGOL, BASIC, FORTRAN	ALGOL, BASIC, FORTRAN
Operating system	Batch, real-time	Batch, real-time	Batch, real-time
Language imp. firmware	No	No	No
Price ($)			
CPU	25250	13400	43900
Central processor			
No. directly addr. wds.	64k	32k	64k
Add time, microseconds	1.0	5.9	1.0
Hardware multiply/divide	Standard	Optional	Standard
Real-time clock or timer	Optional	Optional	Optional
Main storage			
Storage type	Core	Core	Core
Cycle/access time	1.0	1.2	1.0
Min/max capacity, words	16k/64k	16k/32k	16k/1024k
I/O control			
DMA	Standard	Standard	Standard
Maximum I/O rate, word/s	666k	768k	1M
No. ext. interrupt levels	16	16	16
Communications			
Asynchronous	19.2k baud	19.2k baud	19.2k baud
RJE terminals emulated	–	–	–
Peripheral equipment			
Floppy disk drives	Yes	Yes	0.6-1.2M bytes
Disk pack/cart. drives	Cart, 5-10M bytes	Cart, 5-10M bytes	Cart & pack, 5-160M bytes
Drum/fixed head disk storage	Fixed head, 2M bytes	Fixed head, 2M bytes	Fixed head, 0.5-4M bytes
Serial printer	60 cps	60 cps	60 cps
Line printer	1100 lpm	1100 lpm	1100 lpm
Data comm. interface	20k bps	20k bps	20k bps

	Manufacturer and Model		
	Rolm 1650 (AN/UYK-19)	Rolm 1664 (AN/UYK-19)	Rolm 1666 (AN/UYK-19)
Word length, bits	16	16	16
Software			
Compiler	ALGOL, BASIC, FORTRAN	ALGOL, BASIC, FORTRAN	ALGOL, BASIC, FORTRAN
Operating system	Batch, real-time	Batch, real-time	Batch, real-time
Language imp. firmware	No	No	No
Price ($)			
CPU	26250	39450	48900
Central processor			
No. directly addr. wds.	32k	64k	64k
Add time, microseconds	1.05	1.0	1.0
Hardware multiply/divide	Standard	Standard	Standard
Real-time clock or timer	Optional	Optional	Optional
Main storage			
Storage type	Core	Core	Core
Cycle/access time	1.0/0.5	1.0/0.5	1.0/0.5
Min/max capacity, words	16k/32k	16k/64k	16k/1024k
I/O control			
DMA	Standard	Standard	Standard
Maximum I/O rate, word/s	666k	1M	1M
No. ext. interrupt levels	16	16	16
Communications			
Asynchronous	19.2k baud	19.2k baud	19.2k baud
RJE terminals emulated	-	-	None
Peripheral equipment			
Floppy disk drives	Yes	Yes	Yes, 0.6-1.2M bytes
Disk pack/cart. drives	Cart, 5-10M bytes	Cart, 5-10M bytes	Pack & cart, 5-160M bytes
Drum/fixed head disk storage	Fixed head, 2M bytes	Fixed head, 2M bytes	Fixed head, 0.5-4M bytes
Serial printer	60 cps	60 cps	60 cps
Line printer	1100 lpm	1100 lpm	1100 lpm
Data comm. interface	20k bps	20k bps	20k bps

	Manufacturer and Model		
	Rolm MSE-30 Mil-Spec Eclipse	Sperry Univac V77-200	Sperry Univac V77-400
Word length, bits	16	16	16
<u>Software</u>			
Compiler	ALGOL, BASIC, PL/1, FORTRAN	FORTRAN IV, RPG II, PASCAL	FORTRAN IV, RPG II, COBOL, PASCAL
Operating system	Time-sharing, real-time, batch	Batch, real-time	Batch, real-time
Language imp. firmware	No	No	No
<u>Price ($)</u>			
CPU	135000	5350 (8k words)	7850 (8k words)
<u>Central processor</u>			
No. directly addr. wds.	32k	32k	32k
Add time, microseconds	0.5	2.31	2.64
Hardware multiply/divide	Standard	Standard	Standard
Real-time clock or timer	Optional	Standard	Standard
<u>Main storage</u>			
Storage type	Core	MOS	MOS
Cycle/access time	1.0/0.5	0.66/0.56	0.66/0.56
Min/max capacity, words	32k/1024k	8k/32k	8k/1024k
<u>I/O control</u>			
DMA	Standard	Standard	Standard
Maximum I/O rate, word/s	800,000	319k	1.5M
No. ext. interrupt levels	16	8-64	8-64
<u>Communications</u>			
Asynchronous	48×19.2k baud	9600 bps	9600 bps
RJE terminals emulated	IBM 3780	HASP + 1004	HASP + 1004
<u>Peripheral equipment</u>			
Floppy disk drives	2.4M bytes	Yes	Yes
Disk pack/cart. drives	Pack, 8×536M bytes	Both, 10M-40M	Both, 10M-1.6G bytes
Drum/fixed head disk storage	Fixed, 2×4M bytes	No	No
Serial printer	Yes	200 cps	200 cps
Line printer	yes	300-600 lpm	300-600 lpm
Data comm. interface	Yes	50k bytes	50k bytes

	Manufacturer and Model		
	Sperry Univac V77-600	Sperry Univac V77-800	STC Systems Ultimac 2000
Word length, bits	16	16	16
Software			
Compiler	FORTRAN IV, RPG II, COBOL, PASCAL	FORTRAN IV, RPG II, COBOL, PASCAL	BASIC
Operating system	Batch, real-time, multitasking	Batch, real-time, multitasking	Real-time
Language imp. firmware	No	No	No
Price ($)			
CPU	13950 (16k words)	33000 (128k words)	7800
Central processor			
No. directly addr. wds.	2048	2048	256
Add time, microseconds	0.66-2.15	0.45	0.7
Hardware multiply/divide	Standard	Standard	Optional
Real-time clock or timer	Standard	Standard	Standard
Main storage			
Storage type	MOS	MOS	Core
Cycle/access time	0.66/0.56	0.66/0.375	0.7/0.35
Min/max capacity, words	16k/1024k	64k/1024k	32k/48k
I/O control			
DMA	Standard	Standard	Standard
Maximum I/O rate, word/s	1.51M	2.65k	1.1M
No. ext. interrupt levels	8-64	8-64	16
Communications			
Asynchronous	9600 bps	9600 bps	Opt, 9600 bps
RJE terminals emulated	HASP + 1004	HASP + 1004	IBM 2780/3780
Peripheral equipment			
Floppy disk drives	No	Yes	No
Disk pack/cart. drives	Both, 10M-1.6G bytes	Both, 10M-1.6G bytes	Pack, 12-24M bytes
Drum/fixed head disk storage	No	No	No
Serial printer	200 cps	200 cps	165 cps
Line printer	300-600 lpm	300-600 lpm	150-900 lpm
Data comm. interface	50k bytes	50k bytes	300-2400 bps

	Manufacturer and Model		
	STC Systems Ultimac 3000	STC Systems Ultimac 4000	STC Systems Personna-data
Word length, bits	16	16	16
Software			
Compiler	BASIC	BASIC	BASIC
Operating system	Real-time	Real-time	Real-time
Language imp. firmware	No	No	No
Price ($)			
CPU	17700	Contact vendor	17700
Central processor			
No. directly addr. wds.	256	256	256
Add time, microseconds	0.7	0.7	0.7
Hardware multiply/divide	Optional	Optional	Optional
Real-time clock or timer	Standard	Standard	Standard
Main storage			
Storage type	Core	Core	Core
Cycle/access time	0.7/0.35	0.7/0.35	0.7/0.35
Min/max capacity, words	32k/256k	32k/256k	32k/256k
I/O control			
DMA	Standard	Standard	Standard
Maximum I/O rate, word/s	1.1M	1.1M	1.1M
No. ext. interrupt levels	16	16	16
Communications			
Asynchronous	Opt, 9600 bps	Opt, 9600 bps	Opt, 9600 bps
RJE terminals emulated	IBM 2780/3780	IBM 2780/3780	IBM 2780/3780
Peripheral equipment			
Floppy disk drives	No	No	No
Disk pack/cart. drives	Pack, 32-320M bytes	Pack, 32-320M bytes	Pack, 12-320M bytes
Drum/fixed head disk storage	No	No	No
Serial printer	165 cps	165 cps	165 cps
Line printer	150-900 lpm	150-900 lpm	150-900 lpm
Data comm. interface	300-2400 bps	300-2400 bps	300-2400 bps

	Manufacturer and Model		
	Systems Engineering Laboratories 32/30A	Systems Engineering Laboratories 32/55	Systems Engineering Laboratories 32/57
Word length, bits	32 + 7	32 + 7	32 + 7
Software			
Compiler	FORTRAN, COBOL, BASIC	FORTRAN, COBOL, BASIC	FORTRAN, COBOL, BASIC
Operating system	Real-time, interactive, multibatch	Batch, real-time	Real-time, interactive, multibatch
Language imp. firmware	No	No	FORTRAN RTL (part)
Price ($)			
CPU	25100 (128k bytes)	53900 (128k bytes)	39500 (256k bytes)
Central processor			
No. directly addr. wds.	128k	128k	128k
Add time, microseconds	0.6/1.2	0.6/1.2	0.6/1.2
Hardware multiply/divide	Standard	Standard	Standard
Real-time clock or timer	Standard	Standard	Standard
Main storage			
Storage type	MOS	Core	MOS
Cycle/access time	0.6/0.3	0.6/0.3	0.6/0.3
Min/max capacity, words	32k, 64k/256k	8k/256k	64k/256k
I/O control			
DMA	Standard	Standard	Standard
Maximum I/O rate, word/s	6.67M	6.67M	6.67M
No. ext. interrupt levels	16	16-112	16-112
Communications			
Asynchronous	Opt, 38.4 bps	Opt, 38.4 bps	Opt, 38.4 bps
RJE terminals emulated	HASP terminals	HASP terminals	HASP terminals
Peripheral equipment			
Floppy disk drives	No	No	No
Disk pack/cart. drives	Both, 10-1200M bytes	Both, 10-1200M bytes	Both, 10M-19.2G bytes
Drum/fixed head disk storage	Fixed head, 5-40M bytes	Fixed head, 4-16M bytes	Fixed head, 5-40M bytes
Serial printer	340 cps	340 cps	340 cps
Line printer	300-900 lpm	300-900 lpm	300-900 lpm
Data comm. interface	40k bps	40k bps	40k bps

	Manufacturer and Model		
	Systems Engineering Laboratories 32/77	Systems Engineering Laboratories 32/75	Systems Engineering Laboratories VPS 3200
Word length, bits	32 + 7	32 + 4	32 + 7
Software			
Compiler	FORTRAN, COBOL, BASIC	FORTRAN, COBOL, BASIC	FORTRAN, COBOL, BASIC
Operating system	Real-time, interactive, multibatch	Real-time, interactive, multibatch	Real-time, interactive, multivector batch
Language imp. firmware	FORTRAN RTL (part)	FORTRAN RTL (part)	FORTRAN RTL (part)
Price ($)			
CPU	46300 (256k bytes)	72300 (128k bytes)	790000
Central processor			
No. directly addr. wds.	128k	128k	128k
Add time, microseconds	0.6/1.2	0.6/1.2	(See comments)
Hardware multiply/divide	Standard	Standard	Standard
Real-time clock or timer	Standard	Standard	Standard
Main storage			
Storage type	MOS	MOS	MOS
Cycle/access time	0.6/0.3	0.6/0.3	0.6/0.3
Min/max capacity, words	64k/4096k	32k/2048k	64k/4096k
I/O control			
DMA	Standard	Standard	Standard
Maximum I/O rate, word/s	6.67M	6.67M	6.67M
No. ext. interrupt levels	16-112	16-112	16-112/192
Communications			
Asynchronous	Opt, 38.4 bps	Opt, 38.4 bps	Opt, 38.4 bps
RJE terminals emulated	HASP terminals	HASP terminals	HASP terminals
Peripheral equipment			
Floppy disk drives	No	No	No
Disk pack/cart. drives	Both, 10M-19.2G bytes	Both, 10M-19G bytes	Both, 1-19.26G bytes
Drum/fixed head disk storage	Fixed head, 5-40M bytes	Fixed head, 5-40M bytes	Fixed head, 5-40M bytes
Serial printer	340 cps	340 cps	340 cps
Line printer	300-900 lpm	300-900 lpm	300-900 lpm
Data comm. interface	40k bps	40k bps	40k bps
Comments			Includes a 32/77 CPU for scalar arithmetic and a VPU for vector arithmetic; software includes SNAP II vector processing executive and array.

	Manufacturer and Model		
	Systems Engineering Laboratories VPS 3300	Systems Engineering Laboratories VPS 6400	Tandem Computers T16/1102
Word length, bits	32 + 7	32 + 4	16 + 1
Software			
Compiler	FORTRAN, COBOL, BASIC	FORTRAN, COBOL, BASIC	COBOL, TAL, FORTRAN
Operating system	Real-time, interactive, multivector	Real-time, interactive, multivector	Multiprocessing, multiprog, virt
Language imp. firmware	FORTRAN RTL (part)	FORTRAN RTL (part)	Partially
Price ($)			
CPU	85000	137500	20400
Central processor			
No. directly addr. wds.	128k	128k	128k
Add time, microseconds	(See comments)	(See comments)	0.5
Hardware multiply/divide	Standard	Standard	Standard
Real-time clock or timer	Standard	Standard	Standard
Main storage			
Storage type	MOS	MOS	Core
Cycle/access time	0.6/0.3	0.6/0.3	0.8/0.5
Min/max capacity, words	64k/4096k	64k/4096k	32k/256k
I/O control			
DMA	Standard	Standard	Standard
Maximum I/O rate, word/s	6.67M	6.67M	NA
No. ext. interrupt levels	16-112/192	16-112/192	16
Communications			
Asynchronous	Opt, 38.4k bps	Opt, 38.4k bps	Opt, 50-19.2k
RJE terminals emulated	HASP terminals	HASP terminals	2780/3780, 360/370 bps
Peripheral equipment			
Floppy disk drives	No	No	No
Disk pack/cart. drives	Both, 1-19.26G bytes	Both, 1-19.26G bytes	Pack & cart, 10M-24M bytes
Drum/fixed head disk storage	Fixed head, 5-40M bytes	Fixed head, 5-40M bytes	No
Serial printer	340 cps	340 cps	Yes
Line printer	300-900 lpm	300-900 lpm	300-1500 lpm
Data comm. interface	40k bps	40k bps	50-80k bps
Comments	Includes a 32/77 CPU for scalar arithmetic and a VPU for vector arithmetic; software includes SNAP II vector processing executive and array.	Includes a 32/77 CPU for scalar arithmetic and a VPU for vector arithmetic; software includes SNAP II vector processing executive and array.	

	Manufacturer and Model		
	Tandem Computers T16/1403	Terak Corporation 8510/a	Texas Instruments 960B
Word length, bits	16 + 1	16 + 1	16 + 6
Software			
Compiler	COBOL, TAL, FORTRAN	BASIC, FORTRAN, PASCAL	FORTRAN
Operating system	Multiprocessing, multiprog, virt	Real-time	Single-user, real-time, multiprogramming
Language imp. firmware	Partially	No	No
Price ($)			
CPU	22000	7850	4850 (8k words)
Central processor			
No. directly addr. wds.	128k	64k	64k
Add time, microseconds	0.5	3.5	3.6
Hardware multiply/divide	Standard	Standard	Optional
Real-time clock or timer	Standard	Standard	Optional
Main storage			
Storage type	MOS	MOS RAM	MOS
Cycle/access time	0.5/0.5	1.2/1.2	0.75
Min/max capacity, words	32k/256k	64k/64k	8k/64k
I/O control			
DMA	Standard	Standard	Standard
Maximum I/O rate, word/s	NA	–	1.3M
No. ext. interrupt levels	16	2	3-2048
Communications			
Asynchronous	Opt, 50-19.2k bps	Std, 19.2k bps	Up to 9600 bps
RJE terminals emulated	2780/3780, 360/370	None	IBM 360/370
Peripheral equipment			
Floppy disk drives	No	Yes	No
Disk pack/cart. drives	Pack & cart, 10M-24M bytes	No	Cart & pack, 2.28-392M bytes
Drum/fixed head disk storage	No	No	No
Serial printer	Yes	60, 180 cps	30-330 cps
Line printer	300-1500 lpm	No	No
Data comm. interface	50-80k bps	19.2k bps	110-9600 bps

	Manufacturer and Model		
	Texas Instruments 980B	Texas Instruments 990/4	Texas Instruments 990/5
Word length, bits	16 + 6	16 + 1	16 + 1
Software			
Compiler	FORTRAN, BASIC	FORTRAN	FORTRAN, BASIC
Operating system	Single-user, real-time, multiprogramming	Real-time multitask	Real-time multitask
Language imp. firmware	No	No	No
Price ($)			
CPU	5650 (8k words)	1925 (4k words)	3400 (16k words)
Central processor			
No. directly addr. wds.	64k	32k	32k
Add time, microseconds	1.75	4.7	3.5
Hardware multiply/divide	Standard	Standard	Standard
Real-time clock or timer	Optional	Standard	Standard
Main storage			
Storage type	MOS	MOS	MOS
Cycle/access time	0.75	0.67/0.67	0.50/0.50
Min/max capacity, words	8k/64k	4k/28k	16k/32k
I/O control			
DMA	Standard	No	Standard
Maximum I/O rate, word/s	1M	1.5M	1M
No. ext. interrupt levels	4-32	–	16
Communications			
Asynchronous	No	Standard	Standard
RJE terminals emulated	Any RS-232C/20 mA	IBM 2780/3780	IBM 2780/3780
Peripheral equipment			
Floppy disk drives	No	242-968k bytes	242k-4M bytes
Disk pack/cart. drives	Cart & pack, 2.28-392M bytes	No	10M-200M bytes
Drum/fixed head disk storage	No	No	No
Serial printer	30-330 cps	180 cps	180 cps
Line printer	No	300-600 lpm	300-600 lpm
Data comm. interface	110-9600 bps	75-9600 bps	75-9600 bps

Manufacturer and Model	Texas Instruments 990/10	Texas Instruments 990/12	Wang 2200 VS
Word length, bits	16 + 6	16 + 6	32
Software			
Compiler	FORTRAN, BASIC, COBOL, PASCAL, RPG II	FORTRAN, BASIC, COBOL, PASCAL, RPG II	BASIC, COBOL, RPG II, PL/1, FORTRAN
Operating system	Real-time, multitask	Real-time, multitask	Interactive, virtual storage, multiuser
Language imp. firmware	No	No	Fully
Price ($)			
CPU	14675 (64k words)	29050 (128k words)	19000 (128k bytes)
Central processor			
No. directly addr. wds.	32k	32k	512k bytes
Add time, microseconds	3.6	0.552	-
Hardware multiply/divide	Standard	Standard	-
Real-time clock or timer	Standard	Standard	Optional
Main storage			
Storage type	MOS	MOS/cache	MOS/cache
Cycle/access time	0.67/0.67	0.74, 0.15/0.50, 0.15	0.66
Min/max capacity, words	64k/1048k	128k/1048k	128k/2048k bytes
I/O control			
DMA	Standard	Standard	Standard
Maximum I/O rate, word/s	3M	3M	-
No. ext. interrupt levels	16	16	5
Communications			
Asynchronous	Standard	Standard	Up to 9600 bps
RJE terminals emulated	IBM 2780/3780	IBM 2780/3780	2780/3780, HASP
Peripheral equipment			
Floppy disk drives	242k-4M bytes	242k-4M bytes	3154k bytes
Disk pack/cart. drives	10M-800M bytes	10M-800M bytes	Removable, to 90M bytes
Drum/fixed head disk storage	No	No	Fixed, 288M bytes
Serial printer	180 cps	180 cps	30, 120, 200 cps
Line printer	300-600 lpm	300-600 lpm	250-600 lpm
Data comm. interface	75-9600 bps	75-9600 bps	To 9600 bps

ME

8